Astronomical & Geographical

ESSAYS:

CONTAINING,

I.

A FULL AND COMPREHENSIVE VIEW, ON A NEW PLAN, OF THE

General Principles of Astronomy.

II.

THE USE OF THE

CELESTIAL AND TERRESTRIAL

GLOBES,

Exemplified in a greater Variety of Problems, than are to be found in any other Work.

III.

THE DESCRIPTION AND USE

OF THE MOST IMPROVED

PLANETARIUM, TELLURIAN,

AND

LUNARIUM.

IV.

AN INTRODUCTION TO

PRACTICAL ASTRONOMY.

BY THE LATE

GEORGE ADAMS,

MATHEMATICAL INSTRUMENT MAKER TO HIS MAJESTY, AND OPTICIAN TO THE PRINCE OF WALES.

Fourth Edition.

With the Author's last Improvements, Illustrated with elegant Copper-plates.

WHITEHALL:

PRINTED FOR *WILLIAM YOUNG*, BOOKSELLER AND STATIONER N. 52 SOUTH 2d. STREET,

PHILADELPHIA.

1800.

PREFACE.

THE connection of aſtronomy with geography is ſo evident, and both in conjunction ſo neceſſary to a liberal education, that no man will be thought to have deſerved ill of the republic of letters, who has applied his endeavours to diffuſe more univerſally the knowledge of theſe uſeful ſciences, or to render the attainment of them eaſier; for as no branch of literature can be fully comprehended without them, ſo there is none which impreſſes more pleaſing ideas on the mind, or that affords it a more rational entertainment.

The fifth edition of my father's treatiſe on the globes being out of print, I was ſolicited to reprint it. To obviate ſeveral objections to the form in which he had diſpoſed the problems, I was induced to undertake the preſent work, in which they are arranged in a more methodical manner, and a great number added to them. Such facts are alſo occaſionally introduced, ſuch obſervations interſperſed, and ſuch relative information communicated, as it is presumed will excite curiosity, and fix attention.

Having proceeded so far in this work, I found that it was easy to render it subservient to my plan of publishing, from time to time, "ESSAYS, DESCRIBING THE USE OF MATHEMATICAL AND PHILOSOPHICAL INSTRUMENTS;" for the description of those which have been contrived to smooth the path to the science of astronomy, or to facilitate the practice of the arts depending on it, could no where be introduced with so much propriety, as in a work which treated of it's elementary principles.

To further this design, it was necessary to prefix an introduction to astronomy. This is divided into three parts. In the first, the pupil is supposed to be placed in the sun, the center of the solar system: from this situation he considers the motion of the heavenly host, and finds that all is regular and harmonious. In the second part, his attention is directed to the appearances of the planetary bodies, as observed from the earth. It were to be wished that the tutor would at this part exhibit to his pupil the various phenomena in the heavens themselves: by teaching him thus to observe for himself, he would not only raiſe his curioſity, but ſo fix the impreſſions which the objects have made on his mind, that by proper cultivation they would prove a fruitful ſource of uſeful employment; and he would thereby alſo gratify that eager deſire after novelty, which continually animates young minds, and furniſh them with objects on which to exerciſe their natural activity. In the third part of this introduction, the received, or Copernican ſyſtem is explained: by this ſyſtem the various phenomena of the heavens are rationally accounted for; it ſhews us how to reconcile the real ſtate of things with the fallacies ariſing from the ſenſes; and teaches us that the irregularities obſervable in the motion of the heavenly bodies, are for the moſt part to be attributed to the ſituation from which they are obſerved. Aſtronomy, in common with other branches of the mathematics, while it ſtrengthens the powers of the mind, reſtrains it from raſh preſumption, and diſpoſes it to a rational aſſent.

The principles of the Copernican ſyſtem are further elucidated in the third eſſay; in which the moſt improved planetarium, lunarium, and tellurian, are deſcribed. Theſe inſtruments, though leſs complicated in their conſtruction, and lefs expenfive to the purchafer, than thofe large ones heretofore made for the fame purpofe, are equally, perhaps better, adapted to explain the general principles of aftronomy. In defcribing them, it was neceffary to re-confider many fubjects which had been previoufly treated; but as they are here placed in another point of view, prefented to the mind under a different form, are generally defcribed in other words, and often with the addition of new matter, it is hoped that thefe repetitions, fo far from being an object of complaint, will be found to contribute to the main intention of this work, by conveying further inftruction, fixing it more deeply in the mind, and rendering that obvious which before might be found difficult.

One part feemed wanting to an introductory treatife on practical aftronomy; fomething that would gently lead the pupil to a knowledge of the practical part of this fcience, a branch of aftronomy to which we are indebted for our prefent knowledge of the heavens, by which geography has been improved, and by which the paffage of fhips over the tracklefs ocean is facilitated.

There is no part of mathematical ſcience more ſimple and eaſy, than the meaſurement of the relative poſitions and diſtances of inacceſſible objects; yet, to the uninſtructed, to determine the diſtance of a ſhip on the ocean, to aſcertain the height of the clouds and meteors that float in the atmoſphere, to fix the latitude and longitude of places, &c. are problems that have ever appeared to be above the reach of human art; they are therefore particularly calculated to engage the attention of young minds, and may be uſed to encourage diligence, and reward application.

To introduce the pupil to this branch of aſtronomy, I have deſcribed two inſtruments, each of which is ſimple in it's conſtruction, and of ſmall expence. By theſe he may find the diſtance of any inacceſſible object, the height of a ſpire, a mountain, or any other elevation; learn to plot a field; aſcertain the altitude of a cloud, a fire-ball, or any other meteor; determine with accuracy the hour of the day, the latitude or longitude of a place, with many other curious problems. In the ſelection of theſe, for the firſt edition, I have to acknowledge the aſſiſtance I received from an ingenious friend.

N. B. The different Eſſays in this firſt American Edition are printed ſo as to be bound or purchaſed in one volume, or ſeparately, as may be moſt agreeable; therefore the folios are arranged accordingly; viz. the numbers on the top of the page, to ſuit thoſe who wiſh to bind or purchaſe ſeparately; the numbers at the foot, thoſe who chuſe the whole in one volume: of courſe the *references* and *contents* refer always to the *number* at the *foot* of the *page*.

The Binder

Will obſerve that the figures following the Signatures, ſerve as a guide to collate the work.

TABLE OF CONTENTS.

ASTRONOMICAL ESSAYS.

ESSAY I.

PART I.

MANKIND have in all ages been defirous of forming rational conceptions of the nature and motion of thofe bodies that appear in the vaft concave above their heads. Amidft the infinite variety of objects which furround them on every fide, the heavenly bodies muft have been amongft thofe which firft attracted their attention. They are of all objects the moft confpicuous, the moft important, and the moft beautiful.

Aftronomy inftructs us in the laws, or rules, that govern and direct the motions of the heavenly hoft. It weighs and confiders the powers by which they circulate in their orbs. It enables us to difcover their fize, determine their diſtance, explain their various phenomena, and correct the fallacies of the ſenſes by the light of truth.

Aſtronomy is not merely a ſpeculative ſcience; it's uſe is as extenſive, as it's reſearches are ſublime. Navigation owns it for it's guide: by it commerce has been extended, and geography improved. It is aſtronomical obſervations that form the baſis of geography. Thus it has co-operated with other cauſes in the greateſt of all works, the diffuſion of knowledge, and the civilization of man.

As in order to attain an accurate idea of any piece of mechaniſm, it is beſt to begin our inveſtigations by an examination of thoſe parts which give motion to the reſt, the primary cauſes of thoſe effects for which the machine was made; ſo the young pupil will more eaſily gain a juſt idea of the motion of the heavenly bodies, by conſidering them as ſeen from the ſun, the center of our ſyſtem, and the principal agent uſed by the *Lord of nature*, for conducting and regulating the planetary ſyſtem.

It will not be difficult, after this, to inform him how thoſe appearances are to be accounted for, that ariſe from his particular ſituation; whence he views the heavens from a point which is not in the center of the ſyſtem, and is conſequently the ſource of many apparent irregularities. This knowledge attained, it will then be eaſy to prove to him, that the real and apparent motions of the heavenly bodies are frequently the reverſe of each other. For being by this means put into poſſeſſion of the univerſals of this ſcience, the knowledge of particulars will be rendered facile and clear.

OF THE SOLAR SYSTEM, AS SEEN BY A SPECTATOR SUPPOSED TO BE PLACED IN THE SUN.

As the center of the ſyſtem is the only place from which the motion of the planets can be truly ſeen, let us ſuppoſe *an obſerver* placed in the center of the ſun. In this ſituation he will ſee at one view all the heavens, which will appear to him perfectly ſpherical, the ſtars being ſo many lucid points in the concave ſurface of the ſphere, whoſe center is the ſun, or, in the preſent inſtance, the eye of the obſerver.

Our ſpectator will not, however, immediately conclude from appearances, either that the heavens are really ſpherical, or that the ſun is in the center of that ſphere, or that the ſtars are all at an equal diſtance from him; having been previouſly taught by experience and obſervation, that while he remains in the ſame place, he cannot judge properly of the diſtance of ſurrounding objects, at leaſt of thoſe which are placed beyond the ordinary reach of his view. When objects are removed beyond the diſtances we are accuſtomed to, the principles by which we form our general judgment fail us ; and we can only tell which is neareſt, or which is furtheſt, either by our own motion, or that of the objects.

To illuſtrate this, let us ſuppoſe a number of lamps to be placed irregularly, at different diſtances from the eye, in a dark night. Now if in this caſe we ſuppoſe the darkneſs to be ſo complete, that no intermediate objects could be ſeen, no difference in colour diſcerned, nor any convergence towards the point of ſight be perceived ; our judgment could not aſſiſt us in diſtinguiſhing the diſtance of one from the other, and they would therefore all ſeem to be at an equal diſtance from the ſpectator.

For the ſame reaſon, the ſun and moon, the ſtars and planets, appear to be all at an equal diſtance from us ; though it is highly probable, that ſome of the ſtars are many millions of times nearer to us than others. The ſun is demonſtrated to be nearer than any of the ſtars. The moon and ſome of the planets are known by occular proof to be nearer to us than the ſun, becauſe they ſometimes come between it and our eye, and hide the whole, or a great part of his difk, from our view. They all, however, appear equally diftant, and as if placed in the furface of a fphere, whereof our eye is the center. In whatever place, therefore, the fpectator refides, whether it be on this earth, in the fun, or in the regions of Saturn, he will confider that place as the middle point of the univerfe, and the center of the world; for it will be to him the center of a fpherical furface, in which all diftant bodies appear to be placed.

Thefe things being rendered plain, the pupil may proceed to confider the obfervations of the folar fpectator; to whom, as we have already obferved, the heavens will appear as the furface of a concave fphere, concentrical to his eye: in this furface he will difcover an innumerable hoft of fixed ftars, which will for fome time engage his attention, before he difcovers that they may be diftinguifhed into two kinds; the one difperfed through the whole heavens, differing in their degree of brightnefs, but remaining always at the fame relative diftance from each other. Thefe he will therefore call *fixed ftars*, or only *ftars*. Befides thefe, he will find fome others moving among the foregoing with different velocities, which he will call *wandering ftars*, or *planets*.

Of the Celestial Signs and Constellations.

Having proceeded thus far, our ſpectator will endeavour to find out ſome method of diſtinguiſhing the ſtars from each other; concluding, that as they do not change their relative poſitions one to the other, he may eaſily make an exact deſcription of them, and by repeated obſervations determine the poſition and order which ſubſiſt among them.

That he may avoid confuſion in deſcription, and be able to point out any particular ſtar, without being obliged to give a name to each, he will divide them into ſeveral parcels; to each of theſe parcels he will aſſign a figure at pleaſure; theſe aſſemblages, or groupes of ſtars, he will call *conſtellations*. Thus a number of ſtars near the north pole is called the bear, becauſe the ſtars which compoſe it are at ſuch diſtances from each other, that they may fall within the figure of a bear. Another conſtellation is called the ſhip, becauſe that collection of ſtars, which compoſe it, is repreſented upon a cleleſtial globe as comprized within ſome part of the figure of a ſhip.

As the fixed ſtars will appear to our obſerver of different degrees of magnitude and ſplendor, he will divide them into different claſſes. Thoſe which ſeem the largeſt and brighteſt, he will call ſtars of the firſt magnitude; the ſmalleſt that we can ſee with the naked eye, are called ſtars of the ſixth magnitude; and the intermediate ones, according to their different apparent ſizes he will call of the ſecond, third, fourth, or fifth magnitudes. Thoſe ſtars, which cannot be ſeen without the aſſiſtance of a teleſcope, are not reckoned in any of theſe claſſes, and are called *teleſcopic ſtars.*

By a knowledge of the fixed ſtars and their poſitions, our obſerver will obtain ſo many fixed points, by which he may obſerve the motions of the planets, and the relation of theſe motions to each other; he will uſe them as ſo many landmarks, (if the word may be allowed) by which the ſituations of other celeſtial bodies may be aſcertained, and the varieties to which they are ſubject be obſerved. For from the ſame place, the motions of the heavenly bodies can only be eſtimated by the angle formed at the ſpectator's eye by the ſpace which the moving body paſſes over.

To meaſure the ſpaces, the ſtars muſt be uſed, and conſidered as ſo many luminous points fixed in the concavity of a ſphere, whoſe radius is indefinite, and of which the obſerver's eye is the center. We may learn from hence the neceſſity of forming an exact *catalogue of the ſtars*, and of determining their poſitions with accuracy and care. With ſuch a catalogue, the ſcience of aſtronomy begins.

Although to thoſe who are unacquainted with the nature of celeſtial obſervation, it might at firſt ſight appear almoſt impoſſible to number the ſtars; yet their relative ſituations have been ſo carefully obſerved by aſtronomers, that they have not only been numbered, but even their places in the heavens have been aſcertained with greater accuracy, than the relative ſituation of moſt places on the ſurface of the earth.

The greateſt number of ſtars that are viſible to the naked eye, are to be ſeen on a winter's night, when the air is clear, and no moon appears. But even then a good eye can ſcarce diſtinguiſh more than one thouſand at a time in the viſible hemiſphere: for though on ſuch a night they appear to be almoſt innumerable, this appearance is a deception, that ariſes from our viewing them in a tranſient and confuſed manner; whereas, if we view them diſtinctly, and only conſider a ſmall portion of the heavens at a time, and after ſome attention to the ſituation of the remarkable ſtars contained in that portion, begin to count, we ſhall be ſurprized at the ſmallneſs of their number, and the eaſe with which they may be enumerated.

The number of the ancient conſtellations was 48; in theſe were included 1022 ſtars. Many conſtellations have been added by modren aſtronomers; ſo that the catalogues of Flamſteed and De la Caille, when added together, are found to contain near five thouſand ſtars. The names of the conſtellations, their ſituation in the heavens, with other particulars, are beſt learned by ſtudying the artificial repreſentation of the heavens, a celeſtial globe.

The galaxy or milky way muſt not be neglected; it is one of the moſt remarkable appearances in the heavens; it is a broad circle of a whitiſh hue, in ſome places it is double, but for the moſt part conſiſts of a ſingle path ſurrounding the whole celeſtial concave. The great Galileo diſcovered by the teleſcope, that the portion of the heavens which this circle paſſes through, was every where filled with an infinite multitude of exceeding ſmall ſtars, too ſmall to be diſcovered by the naked eye; but by the combination of their light diffuſing a ſhining whiteneſs through the heavens. Mr. Brydone ſays, that when he was at the top of mount Etna, the milky way had the moſt beautiful effect, appearing like a pure flame that ſhot acroſs the heavens.

The ſtars appear of a ſenſible magnitude to the naked eye, becauſe the retina is not only affected by the rays of light which are emitted directly from them, but by many thousands more, which, falling upon our eyelashes, and upon the visible ærial particles about us, are reflected into our eyes so strongly, as to excite vibrations, not only in those points of the retina, where the real images of the stars are formed, but also in other parts round about it. This makes us imagine the stars to be much bigger, than they would be if we saw them only by the few rays which come directly from them to our eyes, without being intermixed with others. Any one may be made sensible of this, by looking at a star of the first magnitude, through a long narrow tube; which, though it takes in as much of the sky as would hold a thousand of such stars, scarce renders that one visible.

The number of the stars almost infinitely exceeds what we have yet been speaking of. An ordinary telescope will discover, in several parts of the heavens, ten times as many stars as are visible to the naked eye. Hooke, in his Micrographia, says, that with a telescope of twelve feet he discovered seventy-eight stars among the Pleiades, and with a more perfect telescope, many more. Galileo reckoned eighty in the space between the belt and the sword of Orion, and above five hundred more in another part of the same constellation, within the compafs of one or two degrees fquare. Antonia Maria de Rheita counted in the fame conftellation above two thoufand ftars. Future improvements in telefcopes may enable us to difcover numberlefs ftars that are now invifible; and many more there may be, which are too remote to be feen through telefcopes, even when they have received their ultimate improvement. Dr. Herfchel, to whofe ingenuity and affiduity the aftronomical world is fo much indebted, and whofe enthufiaftic ardor has revived the fpirit of difcoveries, of which we fhall fpeak more largely in another part of this effay, has evinced what may be effected by improvements in the inftruments of obfervation. In fpeaking here of his difcoveries, I fhall ufe the words of M. de la Lande.* "In paffing rapidly over the heavens with his new telefcope, the univerfe increafed under his eye; 44000 ftars, feen in the fpace of a few degrees, feemed to indicate that there were feventy-five millions in the heavens." He has alfo fhewn that many ftars, which to the eye, or through ordinary glaffes, appear fingle, do in fact confift of two or more ftars. The galaxy or *milky way* owes it's light entirely to the multitude of fmall ftars, placed fo clofe as not to be difcoverable even by an ordinary telefcope. The *nebulæ*,

*Memoires de l'Academie de Dyon, 1785.

or ſmall whitiſh ſpecks, diſcerned by means of teleſcopes, owe their origin to the ſame cauſe; former aſtronomers could only reckon 103, Dr. Herſchel has diſcovered upwards of 1250 of theſe cluſters, beſides a ſpecies which he calls planetary nebulæ. But what are all theſe, when compared to thoſe that fill the whole expanſe, the boundleſs fields of ether! Indeed, the immenſity of the univerſe muſt contain ſuch numbers, as would exceed the utmoſt ſtretch of the human imagination. For who can ſay, how far the univerſe extends, or where are the limits of it? where the Creator ſtayed "his rappid wheels;" or where he "fixed the golden compaſſes?"

Of the Planets, as seen from the Sun.

Our ſolar obſerver having attained a competent knowledge of the fixed ſtars, will now apply himſelf to conſider the planets: theſe, as we have already obſerved, he will ſoon diſtinguiſh, by their motion, from the fixed ſtars; the ſtars always remaining in their places, but the planets will be ſeen paſſing by them with unequal velocities. Thus on obſerving the earth, for inſtance, he will find it moving among the fixed ſtars, and approaching nearer and nearer to the more eaſtern ones; in a year's time it will complete it's revolution, and return to the ſame place again.

He will find *ſeven* of theſe bodies revolving round the ſun, to each of which he will aſſign a name, calling the ſwifteſt *Mercury*, denominating the others in order, according to their velocities, as *Venus*, then the *Earth*, and afterwards *Mars*, *Jupiter*, *Saturn*, and the *Georgium Sidus*.

Proceeding with attention in thus exploring and examining the heavens, he will perceive that the earth is always accompanied by a ſmall ſtar, Jupiter by four, Saturn by ſeven, and the Georgium Sidus by two: theſe ſometimes precede, at others follow; now paſs before, and then behind the planets they reſpectively attend. Theſe ſmall bodies he will call *ſecondary planets*, *ſatellites*, or *moons*.

The obſerver, by remarking the exact time when each planet paſſes over ſome fixed ſtar, and the time they employ from their ſetting out, to their return to the ſame ſtar again, will find the times elapſing between each ſucceſſive return of the ſame planet to the ſame ſtar, to be equal; and he would ſay, that the ſeveral planets deſcribe circles in different periods; but that each of them always completes it's own circle in the ſame ſpace of time.

He will further obſerve, that there are certain bodies, which at their firſt appearance are ſmall, obſcure, ill defined, and that move very ſlow, but which afterwards increaſe in magnitude, light, and velocity, until they arrive at a certain ſize, when they loſe theſe properties, and diminiſh in the ſame manner as they before augmented, and at laſt diſappear. To theſe bodies, which he will find in all the regions of the heavens, moving in different directions, he will give the name of *comets*.

Of the Paths of the Planets.

Our obſerver will take notice, that the planets run ſucceſſively through thoſe conſtellations which he has denominated, *Aries*, *Taurus*, *Gemini*, *Cancer*, *Leo*, *Virgo*, *Libra*, *Scorpio*, *Sagittarius*, *Capricornus*, *Aquarius*, *Piſces*; and that they never move out of a certain ſpace, or zone, of the heavens, which we will call the *zodiac*.

He will find, by proceeding in his obſervation, that the orbits of the planets are not all in the ſame plane, but that they croſs each other in different parts of the heavens; ſo that if he makes the orbit of any one planet a ſtandard, and conſiders it as having no obliquity, he would judge the paths of all the reſt to be inclined to it; each planet having one half of it's path on one ſide, and the other half on the oppoſite ſide of the ſtandard path, or orbit. Aſtronomers generally aſſume the earth's orbit, as the ſtandard from which to compute the inclination of the others, and cal it the *ecliptic*. The points, where the orbits interfect each other, are called the *nodes*.

This inclination of the orbits to each other, may be rendered more familiar to the imagination,* by taking as many hoops as there are planets, with a wire thruft through each, and thereby joined to that hoop which reprefents the ecliptic; the other hoops may be then fet more or lefs obliquely to the reprefentative of the ecliptic.

The feveral orbits do not crofs or interfect the ecliptic in the fame point, or at the fame angles; but their nodes, or interfections, are at different parts of the ecliptic.

It fhould, however, be obferved here, that in fpeaking of the orbits of the planets, nothing more is meant by this term, than the paths they pafs through in the open fpace in which they move, and in which they are retained by a celeftial but continuous mechanifm.

Of the Motion of the Planets round their Axis.

By attentively confidering, with a telefcope, the furface of the primary planets, our folar obferver will find, that fome parts, or *fpots*, are more obfcure than others. By continued obfervation he will find, that thefe fpots change their

* Dr. Watts's Aftronomy.

places, and move from one ſide of the planet to the other; then diſappear for a certain ſpace of time; after which, they again, for a while, become viſible on the ſide where they were firſt ſeen, always continuing the ſame motion nearly in an uniform manner. The diſtance between the ſpots grows wider as they advance from the edge towards the middle of the planet, and then grows narrow again as they paſs from the middle to the other edge. The time they are ſeen on the planet's diſk, is ſomewhat leſs than the time of their diſappearance.

From theſe circumſtances he will conclude, firſt, that theſe ſpots adhere to the body of the planet; and ſecondly, that each planet is a globe turning on it's axis, and has conſequently two motions, one whereby it is moved round it's axis in a ſhort time, the other by which it revolves round the ſun. Theſe motions may be eaſily conceived, by only imagining a ſmall ball to roll round a large ſphere. The firſt of theſe motions, or that of a planet round it's axis, is called the *diurnal motion*; and the ſecond, or it's revolution round the ſun, is called the *annual motion*.

The tutor may in ſome meaſure realize to his pupil the foregoing heliocentric phenomena, by plate I. fig. 1, of the ſolar ſyſtem; or ſtill much better, by means of a planetarium; for by ſuppoſing himſelf on the braſs ball which repreſents the ſun, he will ſee that all the planets move round him in beautiful and harmonious order. If on account of their diſtance he refers their motions to the fixed ſtars, he will ſee how readily the periods of their revolutions may be obtained, by obſerving the time that elapſes between their ſetting out from any fixed point, or ſtar, and their returning to the ſame again. He will alſo ſee, that if the paths of the planets were in one plane, as in the inſtrument, they would all be transferred to one circle in the heavens.

When he underſtands theſe particulars, the tutor may proceed to ſhew him that the motions, which are ſo regular when viewed from the ſun, become intricate and perplexed when viewed from the earth ; and infer from thence that whenever "we examine the works of the Deity at a proper point of diſtance, ſo as to take in the whole of his deſign, we ſee nothing but uniformity, beauty, and preciſion." Thus the heavens preſent us with a plan, which, though inexpreſſibly magnificent, is yet regular beyond the power of invention ; and the volume of the univerſe will be found to be as perfect as it's Author, containing mines of truth for ever opening, fountains of good for ever flowing, an endleſs ſucceſſion of bright, and ſtill brighter exhibitions of the glorious Godhead, anſwering to the nature and idea of infinite fulneſs and perfection.

ESSAY I.

PART II.

OF THE PHENOMENA OF THE HEAVENS, AS SEEN FROM THE EARTH.

THE various appearances of the celeſtial bodies, as ſeen from the earth, are the facts which lay the foundation of all aſtronomical knowledge. To account for, and explain them, is it's principal buſineſs: a true idea of theſe phenomena is therefore a neceſſary ſtep to a knowledge of aſtronomy. Let us therefore ſuppoſe ourſelves in the open air, contemplating the appearances that occur in the heavens.

OF THE APPARENT MOTION OF THE SUN.

The firſt and moſt obvious phenomenon is the daily riſing of the *ſun* in the eaſt, and his ſetting in the weſt; after which the moon and ſtars appear, ſtill keeping the ſame weſterly courfe, till we lofe fight of them altogether. Thefe appearances give rife to what is called the apparent diurnal motion of the heavens.

This cannot be long obferved, before we muft alfo perceive, that the *fun* does not always rife exactly at the fame point of the heavens, his motions deviating confiderably at particular feafons from thofe they perform at other times. Sometimes we perceive him very *high* in the heavens, as if he would come directly over our heads; at other times he is almoft funk in the fouthern part of the heavens. If we commence our obfervations of the fun, for inftance, in the beginning of March, we fhall find him appear to rife more to the northward every day, to continue longer above the horizon, to be more vertical, or higher, at mid-day; this continues till towards the end of June, when he moves backward in the fame manner, and continues this retrograde motion till near the end of December, when he begins to move forwards, and fo on.

It is this change in the fun's place, that occafions him to rife and fet in different parts of the horizon, at different times of the year. It is from hence that his height is fo much greater in fummer, than in winter. In a word, the change of the fun's place in the heavens is the caufe of the different length in the days and nights, and the viciffitudes of the feafons.

As the knowlege of the fun's *apparent* motion is of great importance, and a proper conception of it abſolutely neceſſary, in order to form a true idea of the phenomena of the heavens, the reader will excuſe my dwelling ſomething longer upon it. If on an evening we take notice of ſome fixed ſtar near the place where the ſun ſets, and obſerve it for ſeveral ſucceſſive evenings, we ſhall find that it approaches the ſun from day to day, till at laſt it will diſappear, being effaced by his light, though but a few days before it was at a ſufficient diſtance from him. That it is the ſun which approaches the ſtars, and not the ſtars the ſun, is plain, for this reaſon; the ſtars always riſe and ſet every day at the ſame points of the horizon, oppoſite to the ſame terreſtrial objects, and are always at the ſame diſtance from each other; whereas the ſun is continually changing both the place of it's riſing and ſetting, and it's diſtance from the ſtars.

The ſun advances nearly one degree every day, moving from weſt to eaſt; ſo that in 365 days we ſee the ſame ſtar near the ſetting ſun, as was obſerved to be near him on the ſame day in the preceding year. In other words, the ſun has returned to the place from whence he ſet out, or made what we call his annual revolution.

We cannot indeed obſerve the ſun's motion among the fixed ſtars, becauſe he darkens the heavens by his ſplendor, and effaces the feeble from manhood to old age, will find him ever bufy in endeavouring to find fome reality, to fupply the place of the falfe appearances, by which he has hitherto been deceived.

It is the bufinefs of the prefent part of this effay to correct the errors arifing from appearances, and to point out truth by a brief detail of the principal parts of the Copernican fyftem, which is now univerfally received, becaufe it rationally accounts for, and accords with, the phenomena of the heavens.

"At the appointed time, when it pleafed the fupreme Difpenfer of every good gift to reftore light to a bewildered world, and more particularly to manifeft his wifdom in the fimplicity, as well as in the grandeur of his works, he opened the glorious fcene with a revival of found aftronomy;"* and raifed up Copernicus to difpel the darknefs in which it was then involved.

The *Copernican fyftem* confifts of the fun, feven primary, fourteen fecondary planets, and the comets.

The feven planets, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, and the Georgium Sidus, move round the fun,† in orbits included one within the other, and in the

* Pringle's Six Difcourfes to the Royal Society.

† The fun is not abfolutely at reft, being fubject to a fmall degree of motion, which is confidered in larger works on aftronomy.

order here uſed in mentioning their names, Mercury being that which is neareſt the ſun.

The ſeven, which revolve round the ſun as their center, are called *primary planets.*

The fourteen planets, which revolve round the primary ones as a center, and are at the ſame time carried round the ſun with them, are called *ſecondary planets*, *moons*, or *ſatellites.*

The Georgium Sidus is attended by two moon's, Saturn by ſeven, Jupiter by four, and the Earth by one; all of theſe, excepting the laſt, are inviſible to the naked eye, on account of the ſmallneſs of their ſize, and the greatneſs of their diſtance from us.

Mercury and Venus being within the Earth's orbit, are called *inferior planets ;* but Mars, Jupiter, Saturn, and the Georgium Sidus, being without it, are called *ſuperior planets.*

The orbits of all the planets are elliptical; but as the principal phenomena of the Copernican ſyſtem may be ſatisfactorily illuſtrated, by conſidering them as circular, the latter ſuppoſition is uſually adopted in giving a general idea of the diſpoſition and motion of the heavenly bodies.

Before we enter into a deſcription of the ſolar ſyſtem, it may be neceſſary to define what is meant by the *axis* of a planet; leſt the pupil ſhould conceive them to turn on ſuch material axes, as are uſed in the machines which are contrived to repreſent the planetary ſyſtem.

The *axis of a planet* is a line conceived to be drawn through it's center, and about which it is conceived to turn, in the courſe of it's revolution round the ſun: the extremities of this line terminate in oppoſite points of the ſurface of the planet, and are called it's *poles;* that which points towards the northern part of the heaven, is called the *north pole;* that which points towards the ſouthern, the *ſouth pole.* A ball whirled from the hand into the open air, turns round upon a line within itſelf, while it is moving forward; ſuch a line as this is meant, when we ſpeak of the axis of a planet.

Fig. 1, plate I. repreſents the ſolar ſyſtem, wherein ☉ denotes the ſun; A B the circle which the neareſt planet, Mercury, deſcribes in moving round it; C D that in which Venus moves; F G the orbit of the earth; H K that of Mars; I N that of Jupiter; O P that of Saturn; and Q R that of the Georgium Sidus. Beyond this are the ſtarry heavens.

The ſun and the planets are ſometimes expreſſed by marks or characters, inſtead of writing their names at length. The characters are as follow: ☉ the ſun, ☿ Mercury, ♀ Venus, ⊕ the Earth, ♂ Mars, ♃ Jupiter, ♄ Saturn, ♅ Georgium Sidus.

Of the Sun.

The *ſun* is the center of the ſyſtem, round which the reſt of the planets revolve. It is the firſt and greateſt object of aſtronomical knowledge, and is alone enough to ſtamp a value on the ſcience, to which the ſtudy of it belongs. The ſun is the parent of the ſeaſons; day and night, ſummer and winter, are among it's ſurpriſing effects. All the vegetable creation are the offspring of it's beams; our own lives are ſupported by it's influence. Nature revives, and puts on a new face, when it approaches nearer to us in ſpring; and ſinks into a temporary death at his departure from us in the winter.

Hence the *ſun* was, with propriety, called by the ancients *cor cœli*, the *heart of heaven;* for as the heart is the center of the animal ſyſtem, ſo is the ſun the center of our univerſe. As the heart is the fountain of the blood, and the center of heat and motion; ſo is the ſun the life and heat of the world, and the firſt mover of the mundane ſyſtem. When the heart ceaſes to beat, the circuit of life is at an end; and if the ſun ſhould ceaſe to act, a total ſtagnation would take place throughout the whole frame of nature.

The ſun is placed near the center of the orbits of all the planets, and turns round his axis in twenty-five $\frac{1}{4}$ days. His apparent diameter, at a mean diſtance from the earth, is about thirty-two minutes, twelve ſeconds.

Thoſe who are not accuſtomed to aſtronomical calculation, will be ſurprized at the real magnitude of this luminary; which, on account of it's diſtance from us, appears to the eye not much larger than the moon, which is only an attendant on our earth. When looking at the ſun, they are viewing a globe, whoſe diameter is 890,000 Engliſh miles; whereas the earth is not more in diameter than 7970 miles: ſo that the ſun is about 1,392,500 times bigger than the earth. Thus as it is the fountain of light and heat to all the planets, ſo it alſo far ſurpaſſes them in it's bulk.

If the ſun were every where equally bright, his rotation on his axis would not be perceptible; but by means of the ſpots, which are viſible on his pure and lucid ſurface, we are enabled to diſcover this motion.

When a ſpherical body is near enough to appear of it's true figure, this appearance is owing to the ſhading upon the different parts of it's ſurface: for as a flat circular piece of board, when it is properly ſhaded by painting, will look like a ſpherical body; ſo a ſpherical body appears of it's true ſhape, for the ſame reaſon that the plane board, in the preſent inſtance, appears ſpherical. But if the ſphere be at a great diſtance, this difference of ſhading cannot be diſcerned by the eye, and confequently the fphere will no longer appear of it's true fhape; the fhading is then loft, and it feems like a flat circle.

It is thus with the fun; it appears to us like a bright flat circle, which flat circle is termed the *fun's difk*. By the affiftance of telefcopes *dark fpots* have been obferved on this difk, and found to have a motion from eaft to weft; their velocity is greater when they are at the center, than when they are near the limb. They are feen firft on the eaftern extremity, by degrees they come forwards towards the middle, and fo pafs on till they reach the weftern edge; they then difappear; and after they have lain hid about the fame time that they continued vifible, they appear again as at firft. By this motion we difcover not only the time the fun employs in turning round his axis, but alfo the inclination of his axis to the plane of the ecliptic.*

The page of hiftory informs us, that there have been periods, when the fun has wanted

* The young obferver may view the fpots of the fun with a refracting telefcope of two or three feet, or a reflecting one of 12 inches, 18 inches, or two feet, taking care to guard the eye with a dark glafs, to take off the glaring light: or the image or picture of the fun, with his fpots, may be thrown into a dark room, through a telefcope, and received upon a piece of paper placed nearer or further from the glafs at pleafure.

of it's accuſtomed brightneſs, ſhone with a dim and obſcure light for the ſpace of a whole year. This obſcurity has been ſuppoſed to ariſe from his ſurface being at thoſe times covered with ſpots. Spots have been ſeen that were much larger than the earth.

The ſun is ſuppoſed to have an atmoſphere, which occaſions that appearance which is termed the *zodiacal light*. This light is ſeen at ſome ſeaſons of the year, either a little after ſun-ſet, or a little before ſun-riſe. It is faintly bright, and of a whitiſh colour, reſembling the milky way. In the morning it becomes brighter and larger, as it riſes above the horizon, till the approach of day, which diminiſhes it's ſplendor, and renders it at laſt inviſible. It's figure is that of a flat or lenticular ſpheroid, ſeen in profile. The direction of it's longer axis coincides with the plane of the ſun's equator. But it's length is ſubject to great variation, ſo that the diſtance of it's ſummit from the ſun, varies from 45 to 120 degrees. It is ſeen to the beſt advantage about the ſolſtices. It was firſt deſcribed and named by Caſſini, in 1683; it was noticed by Mr. Childrey, about the year 1650.

Of the inferior Planets, Mercury and Venus.

Of Mercury. ☿

Of all the planets, *Mercury* is the leaſt; at the ſame time, it is that which is neareſt the ſun. It is from his proximity to this globe of light, that he is ſo ſeldom within the ſphere of our obſervation, being loſt in the ſplendor of the ſolar brightneſs; yet it emits a very bright white light. It is oftener ſeen in thoſe parts of the world, which are more ſouthward than that which we inhabit; and oftener to us than to thoſe who live nearer the north pole; for the more oblique the ſphere is, the leſs is the planet's elevation above the horizon.

Mercury never removes but a few degrees from the ſun. The meaſure of a planet's ſeparation, or diſtance, from the ſun, is called it's *elongation.* His greateſt elongation is little more than 28 degrees, or about as far as the moon appears to be from the ſun, the ſecond day after new moon. In ſome of it's revolutions, the elongation is not more than 18 degrees.

Mercury is computed to be 37 millions of miles from the ſun, and to revolve round him in 87 days, 23 hours, and nearly 16 minutes, which is the meaſure of it's year, about one-fourth of our's. As from the nearneſs of this planet to the fun, we neither know the time it revolves round it's axis, nor the inclination of that axis to the plane of it's orbit, we are neceffarily ignorant of the length of it's day and night, or the variety of feafons it may be liable to. Mercury is 3000 miles in diameter. Large as Mercury, when thus confidered, appears to be, it is but an atom, when compared with Jupiter, whofe diameter is 90,000 miles. It's apparent diameter, at a mean diftance from the earth, is 20 feconds.

Mercury is fuppofed to move at the rate of 110,680 miles per hour. The fun is above 26,000,000 times as big as Mercury; fo that it would appear to the inhabitants of Mercury nearly three times larger than it does to us; and it's difk, or face, about feven times the fize we fee it. As the other five planets are above Mercury, their phenomena will be nearly the fame to it as to us. Venus and the earth, when in oppofition to the fun, will fhine with full orbs, and afford a brilliant appearance to the Mercurian fpectator.

Mercury, like the moon, changes it's phafes, according to it's feveral pofitions with refpect to the fun and earth. He never appears quite round or full to us, becaufe his enlightened fide is never turned directly towards us, except when he is fo near the fun, as to become invifible. The times for making the moſt favourable obſervations on this planet, are, when it paſſes before the ſun, and is ſeen traverſing his diſk, in the form of a black ſpot. This paſſage of a planet over the face of the ſun, is called a *tranſit*. It happens in it's lower conjunction, at a particular ſituation of the nodes; which leads us to mention their place in the ecliptic.

The angle formed by the inclination of the orbit of Mercury with the plane of the ecliptic, is 6° 59′; the node from which Mercury aſcends northward, above the plane of the ecliptic, is 16° 1′ 30″; in Taurus, the oppoſite one, 14° 1′ 24″; in Sagittarius, it's nodes move forward about 50″ per year.

If Mercury, at his inferior conjunction, comes to either of his nodes about theſe times, he will appear to *tranſit* over the diſk of the ſun. But in all other parts of his orbit his conjunctions are inviſible, becauſe he either goes above or below the ſun.

Of Venus. ♀

Venus is the brighteſt and largeſt, to appearance, of all the planets, diſtinguiſhed from them all by a ſuperiority of luſtre; her light is of a white colour, and ſo conſiderable, that in a duſky place ſhe projects a ſenſible ſhade.

The diameter of Venus is 7,699 miles; her diſtance from the ſun is 69,500,000 miles; ſhe goes round the ſun in 224 days, 16 hours, 49 minutes, moving at the rate of 80,995 miles per hour. Her motion round her axis has been fixed by ſome at 23h. 22m.; by others at above 24 days. She, like Mercury, conſtantly attends the ſun, never departing from him above 47 or 48 degrees. Like Mercury, ſhe is never ſeen *at midnight*, *or in oppoſition to the ſun*, being viſible only for three or four hours in the morning, or evening, according as ſhe is before or after the ſun.

One would not imagine that this planet, which appears ſo much ſuperior to Saturn in the heavens, is ſo inconſiderable when compared to it; for the diameter of Saturn is nearly 78,000 miles; while, on the other hand, one would ſcarce imagine that Venus, which appears but as a lucid ſpangle in the heavens, was ſo large a globe as ſhe truly is, her diameter being 7,699 miles. It is the *diſtance* which produces theſe effects; which gives and takes away the magnitude of things. Her apparent ſize varies with her diſtance; at ſome ſeaſons ſhe appears nearly 32 times larger than at others.

When this planet is in that part of it's orbit which is weſt of the ſun, that is, from her inferior to her ſuperior conjunction, ſhe rifes before him in the morning, and is called *phofphorus*, or *lucifer*, or the *morning ftar*. When fhe appears eaft of the fun, that is, from her fuperior to her inferior conjunction, fhe fets in the evening after him; or, in other words, fhines in the evening after he fets, and is called *hefperus*, or *vefper*, or the *evening ftar*.

The inhabitants of Venus fee the planet Mercury always accompanying the fun; and he is to them, by turns, an evening or a morning ftar, as Venus is to us. To the fame inhabitants, the fun will appear almoft twice as large as he does to us.

Venus, when viewed through a telefcope, is feldom feen to fhine with a full face; but has phafes, juft like the moon, from the fine thin crefcent to the enlightened hemifphere. Her illuminated part is conftantly turned towards the fun; hence it's horns are turned towards the eaft when it is a morning ftar, and towards the weft when it it an evening ftar. Some aftronomers have thought they perceived a fatellite moving round Venus; but as fucceeding obfervers have not been able to verify their obfervations, they are fuppofed to have originated in error. In obferving the tranfit of Venus, Mr. Dunn, and other gentlemen, faw a penumbra which took place about five feconds before the contact, preceeding the egrefs of the planet; and from thence they concluded, that it had an atmofphere of about 50 geographical miles in height.

We are told, that, when *Copernicus* firft publifhed his account of the folar fyftem, it was objected to him that it could not be true, becaufe, if it was, the inferior planets muft have different *phafes*, according to their different fituation with refpect to the fun and earth; whereas they always appear round to us. The anfwer faid to be made by him, is, that they appear round to the eye by reafon of their diftance; but if we could have a nearer, or more diftinct view of them, *we fhould fee in them the fame phafes we do in the moon.* The invention of telefcopes is faid to have verified this prediction of Copernicus. But it is neither probable, that a defender of the Ptolemaic fyftem fhould make fuch an objection, or Copernicus fuch an anfwer; fince in the Ptolemaic, as well as in the Copernican fyftem, the fhape of thefe planets ought to change, juft as the moon does; confequently, the *mere change of fhape* in the inferior planets is an argument, which, in the common way of urging it, proves *nothing at all* as to the truth or falfhood of the Copernican fyftem. If, befides the changes of fhape made in the inferior planets, we confider the fituation of the planets with refpect to the fun, when thefe changes happen; this, indeed, will fhew us, that the Ptolemaic ſyſtem is falſe,* as will be ſeen in a ſubſequent part of theſe eſſays.

Venus is ſometimes ſeen paſſing over the diſk of the ſun, as a round dark ſpot. Theſe appearances, which are called tranſits, happen very ſeldom; though there have been two within theſe few years, the one in June 1761, the other in June 1769; the next will be in the year 1874.

Of the Earth. ⊕

The next planet that comes before us is the earth that we inhabit; ſmall as it really is when compared to ſome of the other planets, it is to us of the higheſt importance: we wiſh only to attain knowledge of others, that we may find out their relation to this, and from thence learn our connection with the univerſe at large. But when viewed with an eye to *eternity*, it's value to us is heightened in a manner that exceeds expreſſion, and ſurpaſſes all the powers of the human mind. He alone can form ſome idea of it, who in the regions of celeſtial bliſs is become a partaker of the length and breadth, the depth and height, of divine love.

* Rutherford's Syſtem of Natural Philoſophy, vol. 2, p. 781.

The orbit of the earth is placed between thofe of Venus and Mars. The diameter of the earth is 7970 miles; it's diftance from the fun is 96 millions of miles, and goes round him in a year, or 365 days, 6 hours, 9 minutes, moving at the rate of 68,856 miles per hour. It's apparent diameter, as feen from the fun, is about 21 feconds.

It turns round it's axis, from *weft to eaft*, in 24 hours, which occafions the apparent diurnal motion of the fun, and all the heavenly bodies round it, from *eaft to weft*, in the fame time; it is, of courfe, the caufe of their rifing and fetting, of day and night.

The axis of the earth is inclined 23½ degrees to the plane of it's orbit, and keeps in a direction parallel to itfelf, throughout it's annual courfe, which caufes the returns of fpring and fummer, autumn and winter. Thus his *diurnal* motion gives us the grateful viciffitude of night and day, and his *annual* motion the regular fucceffions of feafons.

Of the Moon. ☾

Next to the fun, the *moon* is the moft fplendid and fhining globe in the heavens, the *fatellite*, or infeparable companion of the earth. By diffipating, in fome meafure, the darknefs and horrors of the night; fubdividing the year into months; and regulating the flux and reflux of the ſea; ſhe not only becomes a pleaſing, but a welcome object; an object affording much for ſpeculation to the contemplative mind, of real uſe to the navigator, the traveller, and the huſbandman. The Hebrews, the Greeks, the Romans, and, in general, all the ancients, uſed to aſſemble at the time of new moon, to diſcharge the duties of piety and gratitude for it's manifold uſes.

That the moon appears ſo much larger than the other planets, is owing to her vicinity to us; for to a ſpectator in the ſun ſhe would be ſcarcely viſible, without the aſſiſtance of a teleſcope. Her diſtance is but ſmall from us, when compared with that of the other heavenly bodies; for among theſe, the leaſt abſolute diſtance, when put down in numbers, will appear great, and the ſmalleſt magnitude immenſe.

The moon is 2161 miles in diameter; her bulk is about $\frac{3}{11}$ of the earth's; her diſtance from the center of the earth 240,000 miles; ſhe goes round her orbit in 27 days, 7 hours, 43 minutes, moving at the rate of 2299 miles per hour. The time in going round the earth, reckoning from change to change, is 29 days, 12 hours, 44 minutes. Her apparent diameter at a mean diſtance from the earth is $31' \ 16\frac{1}{2}''$; but as viewed from the ſun, at a mean diſtance about $6''$.

Her orbit is inclined to the ecliptic, in an angle of 5 degrees, 18 minutes, cutting it in two points, which are diametrically oppofite to each other; thefe points are called her *nodes*. *Her nodes have a motion weftward*, or contrary to the order of the figns, making a complete revolution in about 19 years; in which time, each node returns to that point of the ecliptic whence it before receded.

If the moon were a body poffeffing native light, we fhould not perceive any diverfity of appearance; but as fhe fhines entirely by light received from the fun, and reflected by her furface, it follows, that, according to the fituation of the beholder with refpect to the illuminated part, he will fee more or lefs of her reflected beams, for only one half of a globe can be enlightened at once.

Hence, while fhe is making her revolution round the heavens, fhe undergoes great changes in her appearance. She is fometimes on our meridian at midnight, and therefore in that part of the heavens which is oppofite to the fun; in this fituation fhe appears as a complete circle, and it is faid to be *full moon*. As fhe moves eaftward, fhe becomes deficient on the weft fide, and in about $7\frac{1}{3}$ days comes to the meridian, at about fix in the morning, having the appearance of a femicircle, with the convex fide turned towards the fun; in this ftate, her appearance is called the *half moon.* Moving on ſtill eaſtward, ſhe becomes more deficient on the weſt, and has the form of a creſcent, with the convex ſide turned towards the ſun ; this creſcent becomes continually more ſlender, till about fourteen days after the full moon ſhe is ſo near the ſun, that ſhe cannot be ſeen, on account of his great ſplendor. About four days after this diſappearance, ſhe is ſeen in the evening, a little to the eaſtward of the ſun, in the form of a fine creſcent, with the convex ſide turned from the ſun ; moving ſtill to the eaſtward, the creſcent becomes more full ; and when the moon comes to the meridian, about ſix in the evening, ſhe has again the appearance of a bright ſemicircle ; advancing ſtill to the eaſtward ſhe becomes fuller on the eaſt ſide ; at laſt, in about $29\frac{1}{2}$ days, ſhe is again oppoſite to the ſun, and again full.

It frequently happens, that the *moon is eclipſed* when at the *full ;* and that the *ſun is eclipſed* ſome time between the *diſappearance* of the moon in the morning on the weſt ſide of the ſun, and her appearance in the evening on the eaſt ſide of the ſun. The nature of theſe phenomena will be more fully conſidered, when we come to treat particularly of eclipſes.

In every revolution of the moon about the earth, ſhe turns once round upon her axis, and therefore always preſents the ſame face to our view; and as, during her courſe round the earth, the ſun enlightens ſucceſſively every part of her globe only once, conſequently ſhe has but one day in all that time, and her day and night together are as long as our lunar month. As we ſee only one ſide of the moon, we are therefore inviſible to the inhabitants on the oppoſite ſide, without they take a journey to that ſide which is next to us, for which purpoſe ſome of them muſt travel more than 1500 miles.

As the moon illuminates the earth by a light reflected from the ſun, ſhe is reciprocally enlightened, but in a much greater degree, by the earth; for the ſurface is above thirteen times greater than that of the moon; and therefore, ſuppoſing their power of reflecting light to be equal, the earth will reflect thirteen times more light on the moon than ſhe receives from it. When it is what we call new moon, we ſhall appear as a full moon to the Lunarians; as it increaſes in light to us, our's will decreaſe to them: in a word, our earth will exhibit to them the ſame phaſes as ſhe does to us.

We have already obſerved, that from one half of the moon the earth is never ſeen; from the middle of the other half, it is always ſeen over head, turning round almoſt thirty times as quick as the moon does. To her inhabitants, the earth ſeems to be the largeſt body in the univerſe, about thirteen times as large to them, as ſhe does to us. As the earth turns round it's axis, the ſeveral continents and iſlands appear to the Lunarians as ſo many ſpots, of different forms; by theſe ſpots, they may determine the time of the earth's diurnal motion; by theſe ſpots, they may, perhaps, meaſure their time,—they cannot have a better dial.

OF THE SUPERIOR PLANETS.

Mars, *Jupiter*, *Saturn*, and the *Georgium Sidus*, are called *ſuperior planets*, becauſe they are higher in the ſyſtem, or farther from the center of it, than the earth is.

They exhibit ſeveral phenomena, which are very different from thoſe of Mercury and Venus; among other things, they come to our meridian both at noon and midnight, and are never ſeen croſſing the ſun's diſk.

OF MARS. ♂

Mars is the leaſt bright and elegant of all the planets; it's orbit lies between that of the earth and Jupiter, but very diſtant from both. He appears of a duſky reddiſh hue; from the dullneſs of his appearance, many have conjectured that he is encompaſſed with a thick cloudy atmoſphere; his light is not near ſo bright as that of Venus, though he is ſometimes nearly equal to her in ſize.

Mars, which appears ſo inconſiderable in the heavens, is 5,309 miles in diameter. It's diſtance from the ſun is 146,000,000 miles. It goes round the ſun in one year, 321 days, 23 hours, moving at the rate of 55,287 miles per hour. It revolves round it's axis in about 24 hours, 40 minutes. To an inhabitant in Mars, the ſun would appear one-third leſs in diameter than it does to us. It's apparent diameter, as viewed at a mean diſtance from the earth, is 30 ſeconds.

Mars, when in oppoſition to the ſun, is five times nearer to us than when in conjunction. This has a very viſible effect on the appearance of the planet, cauſing him to appear much larger at ſome periods than at others.

The analogy between Mars and the earth is by far the greateſt in the whole ſolar ſyſtem; their diurnal motion is nearly the ſame; the obliquities of their reſpective ecliptics not very different. Of all the ſuperior planets, that of Mars is by far the neareſt like the earth: nor will the Martial year appear ſo diſſimilar to our's, when we compare it with the long duration of the years of Jupiter, Saturn, and the Georgium Sidus. It probably has a conſiderable atmoſphere; for beſides the permanent ſpots on it's ſurface, Dr. Herſchel has often perceived occaſional changes of partial bright belts, and alſo once a darkiſh one in a pretty high latitude; alterations which we can attribute to no other cauſe than the variable diſpoſition of clouds and vapours floating in the atmoſphere of the planet.

A ſpectator in Mars will rarely, if ever, ſee Mercury, except when he ſees it paſſing over the ſun's diſk. Venus will appear to him at about the ſame diſtance from the ſun, as Mercury appears to us. The earth will appear about the ſize of Venus, and never above 48 degrees from the ſun; and will be, by turns, a morning and evening ſtar to the inhabitants of Mars. It appears, from the moſt accurate obſervations, that Mars is a ſpheroid, or flatted ſphere, the equatorial diameter to the polar being in the proportion of about 131 to 127; and there is reaſon to ſuppoſe that all the planets are of this figure.

Of Jupiter. ♃

Jupiter is ſituated ſtill higher in the ſyſtem, revolving round the ſun, between Mars and Saturn. It is the largeſt of all the planets, and eaſily diſtinguiſhed from them by his peculiar magnitude and light. To the naked eye it appears almoſt as large as Venus, but not altogether ſo bright.

Jupiter revolves round it's axis in 9 hours, 56 minutes; it's revolution in it's orbit to the ſame point of the ecliptic is 11 years, 314 days, 10 hours. The diſproportion of Jupiter to the earth, in ſize, is very great; viewing him in the heavens, we conſider him as ſmall in magnitude; whereas he is in reality 90,228 miles in diameter; his diſtance from the ſun is 494,750,000 miles; he moves at the rate of rather more than 29,083 miles per hour. It's apparent diameter, as ſeen at a mean diſtance from the earth, is 39″.

To an eye placed in Jupiter, the ſun would not be a fifth part of the ſize he appears to us, and his diſk be 25 times leſs. Though Jupiter be the largeſt of all the planets, yet it's revolution round it's axis is the ſwifteſt. The polar axis is ſhorter than the equatorial one, and his axis perpendicular to the plane of his orbit.

Jupiter, when in oppoſition to the ſun, is much nearer the earth, than when he is in conjunction with him; at thoſe times he appears alſo larger, and more luminous than at other times.

In Jupiter, the days and nights are of an equal length, each being about five hours long. We have already obſerved, that the axis of his diurnal rotation is nearly at right angles to the plane of his annual one, and confequently there can be fcarce any difference in the feafons ; and here, as far as we may reafon from analogy, we may difcover the footfteps of wifdom : for if the axis of this planet were inclined by any confiderable number of degrees, juft fo many degrees round each pole would, in their turn, be almoft fix years in darknefs ; and as Jupiter is of fuch an amazing fize, in this cafe immenfe regions of land would be uninhabitable.

Jupiter is attended by four fatellites, or moons ; thefe are invifible to the naked eye ; but through a telefcope they make a beautiful appearance. As our moon turns round the earth, enlightening the nights, by reflecting the light fhe receives from the fun ; fo thefe alfo enlighten the nights of Jupiter, and move round him in different periods of times, proportioned to their feveral diftances : and as the moon keeps company with the earth in it's annual revolution round the fun, fo thefe accompany Jupiter in it's courfe round that luminary.

In fpeaking of the fatellites, we diftinguifh them according to their places ; into the firft, the fecond, and fo on ; by the firft, we mean that which is neareft to the planet.

The outermoft of Jupiter's fatellites will appear almoft as big as the moon does to us ; five times the diameter, and twenty-five times the difk of the fun. The four fatellites muft afford a pleaſing ſpectacle to the inhabitants of Jupiter; for ſometimes they will riſe all together, ſometimes be all together on the meridian, ranged one under another, beſides frequent eclipſes. Notwithſtanding the diſtance of Jupiter and his ſatellites from us, the eclipſes thereof are of conſiderable uſe, for aſcertaining with accuracy the longitude of places. From the four ſatellites the inhabitants of Jupiter will have four different kinds of months, and the number of them in their year not leſs than 4,500.

An aſtronomer in Jupiter will never ſee Mercury, Venus, the Earth, or Mars; becauſe, from the immenſe diſtance at which he is placed, they muſt appear to accompany the ſun, and riſe and ſet with him; but then he will have for the objects of obſervation, his own four moons, Saturn, his ring and ſatellites, and probably the Georgium Sidus.

OF SATURN. ♄

Before the diſcovery of the Georgium Sidus, *Saturn* was reckoned the moſt remote planet in our ſyſtem; he ſhines but with a pale feeble light, leſs bright than Jupiter, though leſs ruddy than Mars. The uninformed eye imagines not, when it is directed to this little ſpeck of light, that it is viewing a large and glorious globe, one of the moſt ſtupenduous of the planets, whoſe diameter is nearly 78,000 miles. We need not, however, be ſurprized at the vaſt bulk of Saturn, and it's diſproportion to it's appearance in the heavens; for we are to conſider that all objects decreaſe in their apparent magnitude, in proportion to their diſtance; but the diſtance of Saturn is immenſe; that of the earth from the ſun is 96,000,000 miles; of Saturn, 916,500,000 miles.

The length of a planet's year, or the time of it's revolution round it's orbit, is proportioned to it's diſtance from the ſun. Saturn goes round the ſun in 29 years, 167 days, 6 hours, moving at the rate of rather more than 22,298 miles per hour. His apparent diameter at a mean diſtance from the earth is 16″.

It has not yet been aſcertained with certainty by aſtronomical obſervation, whether Saturn revolves or not upon his axis. The ſun's diſk will appear ninety times leſs to an inhabitant of Saturn, than it does to us; but notwithſtanding the ſun appears ſo ſmall to the inhabitants of the regions of Jupiter and Saturn, the light that he will afford them is much more than would be at firſt ſuppoſed: and calculations have been made, from which it is inferred, that the ſun will afford 500 times as much light to Saturn, as the full moon to us; and 1600 times as much to Jupiter.

To eyes like our's, unaffifted by inftruments, Jupiter and the Georgium Sidus would be the only planets feen from Saturn, to whom Jupiter would fometimes be a morning, fometimes an evening ftar.

One of the firft difcoveries of the telefcope, when brought to a tolerable degree of perfection, was, that Saturn did not appear like other planets. Galileo, in 1610, fuppofed it compofed of 3 ftars, or globes, a larger in the middle, and a fmaller on each fide; and he continued his obfervations till the two leffer ftars difappeared, and this planet looked like the others. Further obfervation fhewed that what Galileo took for two ftars, were parts of a ring. This fingular and curious appendage to the planet Saturn, is a thin, broad, opake ring, encompaffing the body of the planet, without touching it, like the horizon of an artificial globe, appearing double when viewed through a good telefcope. The fpace between the ring and the globe of Saturn, is fuppofed to be rather more than the breadth of the ring, and the greateft diameter of the ring to be in proportion to that of the globe, as 7 to 3; the plane of the ring is inclined to the plane of the ecliptic, in an angle of 30°, and is about 21,000 miles in breadth. It puts on different appearances to us, fometimes being feen quite open, at others only as a line upon the equator.

It is probable, that it will at times caſt a ſhadow over vaſt regions of Saturn's body. The ring of Saturn conſidered as a broad flat ring of ſolid matter, ſuſpended round the body of the planet, and keeping it's place without any connection with the body, is quite different from all other planetary phenomena with which we are acquainted. Of the nature of this ring, various and uncertain were the conjectures of the firſt obſervers; though not more perplexed, than thoſe of the lateſt. Of it's uſe to the inhabitants of Saturn, we are as ignorant as of it's nature: though there are reaſons for ſuppoſing that it would appear to them as little more than a white or bright-coloured cloud. Some of the phenomena of Saturn's ring will be treated of more particularly in another part of this eſſay.

Saturn is not only furniſhed with this beautiful ring, but it has alſo ſeven attendant moons.

Of the Georgium Sidus. ♅

From the time of Huygens and Caſſini, to the diſcovery of the *Georgium Sidus* by Dr. Herſchel, though the intervening ſpace was long, though the number of aſtronomers was increaſed, though aſſiduity in obſerving was aſſiſted by accuracy and perfection in the inſtruments of obſervation, yet no new diſcovery was made in the heavens, the boundaries of our ſyſtem were not enlarged. The inquiſitive mind naturally enquires, why, when the number of thoſe that cultivated the ſcience was increaſed, when the ſcience itſelf was ſo much improved, in practical diſcoveries it was ſo deficient? A ſmall knowledge of the human mind will anſwer the queſtion, and obviate the difficulty. The mind of man has a natural propenſity to indolence; the ardour of it's purſuits, when they are unconnected with ſelfiſh views, are ſoon abated, ſmall difficulties diſcourage, little inconveniences fatigue it, and reaſon ſoon finds excuſes to juſtify, and even applaud this weakneſs. In the preſent inſtance, the unmanageable length of the teleſcopes that were in uſe, and the continual expoſure to the cold air of the night, were the difficulties the aſtronomer had to encounter with; and he ſoon perſuaded himſelf, that the ſame effects would be produced by ſhorter teleſcopes, with equal magnifying power; herein was his miſtake, and hence the reaſon why ſo few diſcoveries have been made ſince the time of Caſſini. A ſimilar inſtance of the retrogradation of ſcience occurs in the hiſtory of the microſcope, as I have ſhewn in my eſſays on that inſtrument.

The Georgium Sidus was diſcovered by Dr. Herſchel, in the year 1781: for this diſcovery he obtained from the Royal Society the honorary recompence of Sir Godfrey Copley's medal. He named the planet in honour of his Majeſty King George III. the Patron of ſcience, who has taken Dr. Herſchel under his patronage, and granted him an annual ſalary. By this munificence he has given ſcope to a very uncommon genius, and enabled him to proſecute his favourite ſtudies with unremitted ardour.

In ſo recent a diſcovery of a planet ſo diſtant, many particulars cannot be expected. It's year it ſuppoſed to be more than 80 ſiderial years; it's diameter 34,299 miles; the inclination of it's orbit 43′ 35″; it's diameter, compared to that of the earth, as 431,769 to 1; in bulk it is 8,049,256 times as large as the earth. It's light is of a blueiſh white colour, and it's brilliancy between that of the moon and Venus.

Though the Georgium Sidus was not known as a planet till the time of Dr. Herſchel, yet there are many reaſons to ſuppoſe it had been ſeen before, but had then been conſidered as a fixed ſtar. Dr. Herſchel's attention was firſt engaged by the ſteadineſs of it's light; this induced him to apply higher magnifying powers to his teleſcope, which increaſed the diameter of it: in two days he obſerved that it's place was changed; he then concluded it was a comet; but in a little time he, with others, determined that it was a planet, from it's vicinity to the ecliptic, the direction of it's motion, being ſtationary in the time, and in ſuch circumſtances as correſpond with ſimilar appearances in other planets.

With a teleſcope, which magnifies about 300 times, it appears to have a very well-defined viſible diſk; but with inſtruments of a ſmaller power it can hardly be diſtinguiſhed from a fixed ſtar between the ſixth and ſeventh magnitude. When the moon is abſent, it may alſo be ſeen by the naked eye.

Dr. Herſchel has ſince diſcovered that it is attended by two ſatellites: a diſcovery which gave him conſiderable pleaſure, as the little ſecondary planets ſeemed to give a dignity to the primary one, and raiſe it into a more conſpicuous ſituation among the great bodies of our ſolar ſyſtem.

As the diſtances of the planets, when marked in miles, are a burden to the memory, aſtronomers often expreſs their mean diſtances in a ſhorter way, by ſuppoſing the diſtance of the earth from the ſun to be divided into ten parts. Mercury may then be eſtimated at four of ſuch parts from the ſun, Venus at ſeven, the earth at ten, Mars at fifteen, Jupiter at fifty-two ſuch parts, Saturn at ninety-five, and the Georgium Sidus 190 parts.

By comparing the periods of the planets, or the time they take to finiſh their revolutions, with their diſtance from the ſun, they are found to obſerve a wonderful harmony and proportion to each other; for the nearer any planet is to the ſun, the ſooner does he finiſh his revolution. And in this there is a conſtant and immutable law, which all the bodies of the univerſe inviolably obſerve in their circulations; namely, *That the ſquares of their periodical times are as the cubes of their diſtances from the center of the orbits about which they regularly perform their motions.* We are indebted to the ſagacity of *Kepler* for the diſcovery of this law; he was indeed one of the firſt founders of modern aſtronomy.

I cannot conclude this general ſurvey of the ſolar ſyſtem better than in the words of that excellent mathematician, Mr. Maclaurin. "The view of nature which is the immediate object of ſenſe, is very imperfect, and of ſmall extent; but by the aſſiſtance of art, and the aid of reaſon, becomes enlarged, till it loſes itſelf in infinity. As magnitude of every ſort, abſtractedly conſidered, is capable of being increaſed to infinity, and is alſo diviſible without end; ſo we find, that in nature the limits of the greateſt and leaſt dimenſions of things are actually placed at an immenſe diſtance from each other.

"We can perceive no bounds of the vaſt

expanſe, in which natural cauſes operate, and fix no limit, or termination, to the univerſe. The objects we commonly call great, vaniſh, when we contemplate the vaſt body of the earth. The terraqueous globe itſelf is loſt in the ſolar ſyſtem; the ſun itſelf dwindles into a ſtar; Saturn's vaſt orbit, and all the orbits of the comets, crowd into a point, when viewed from numberleſs places between the earth and the neareſt fixed ſtars. Other ſun's kindle to illuminate other ſyſtems, where our ſun's rays are unperceived; but they alſo are ſwallowed up in the vaſt expanſe. When we have riſen ſo high, as to leave all definite meaſures far behind us, we find ourſelves no nearer to a term, or limit.

"Our views of nature, however imperfect, ſerve to repreſent to us, in a moſt ſenſible manner, that mighty Power which prevails throughout, acting with a force and efficacy that ſuffers no diminution from the greateſt diſtances of ſpace or intervals of time; and to prove that all things are ordered by infinite wiſdom, and perfect goodneſs: ſcenes which ſhould excite and animate us to correſpond with the general harmony of nature."*

* Maclaurin.

An Explanation of various Phenomena, agreeable to the Copernican System.

Having given a general idea of the Copernican fyftem, and the bodies of which it is compofed, it will be neceffary to enlarge thefe ideas by a more minute defcription of the particular parts, which form this great whole; and to ftrengthen them by the force of that evidence, on which the fyftem is founded.

Of the Figure and Magnitude of the Earth.

The places of the heavenly bodies could not be fettled with accuracy from obfervations made on the furface of the earth, unlefs it's figure and magnitude were previoufly known; and without this knowledge, computations from the obfervations of the heavenly bodies, for afcertaining the fituation of places on the earth, could not be depended on.

I have already obferved, that the appearance of the heavenly bodies is not the fame to the inhabitants of various parts of the earth; that the fun, the moon, and the ftars, rife and fet in Greenland in a manner very different from what they do in the Eaft Indies, and in both places very different to what they do in

England: and as it was natural to attribute the caufe of this change in the apparent face of the heavens, to the figure of the earth, (for appearances muft ever anfwer to the form and ftructure of the things) the nature of this figure was, therefore, one of the firft objects of inquiry among philofophers and aftronomers.

Some of the fages of antiquity concluded, that the earth muft neceffarily be of a fpherical figure, becaufe that figure was, on many accounts, the moft convenient for the earth, as an habitable world: they alfo argued, that this figure was the moft natural, becaufe any body expofed to forces, which tend to one common center, as is the cafe with the earth, would neceffarily affume a round figure. The affent, however, of the modern philofopher to this truth, was not determined by fpeculative reafoning; but on evidence, derived from facts and actual obfervation. From thefe I fhall felect thofe arguments, that I think will have the greateft weight with young minds.

It is known, from the laws of optics and perfpective, that if any body, in all fituations, and under all circumftances, project a *circular fhadow*, that body muft be a globe.

It is alfo known, that eclipfes of the moon are caufed by the fhadow of the earth.

And we find, that whether the *fhadow* be projected towards the east, or the weſt, the north, or the ſouth, under every circumſtance *it is circular:* the body, therefore, that caſts the ſhadow, which is the earth, muſt be of a *globular* figure.

We ſhall obtain another convincing proof of the globular ſhape of the earth, by inquiring in what manner a perſon ſtanding upon the coaſt of the ſea, and waiting for a veſſel which he knows is to arrive, ſees that veſſel. We ſhall find, that he firſt of all, and at the greateſt diſtance, ſees the top of the maſt riſing out of the water; and the appearance is, as if the ſhip was ſwallowed up in the water. As he continues to obſerve the object, more and more of the maſt appears; at length he begins to ſee the top of the deck, and by degrees the whole body of the veſſel. On the other hand, if the ſhip be departing from us, we firſt loſe ſight of the hull, at a greater diſtance the main-ſails diſappear, at a ſtill greater the top-ſail. But if the ſurface of the ſea were a plane, the body of the ſhip, being the largeſt part of it, would be ſeen firſt, and from the greateſt diſtance, and the maſts would not be viſible till it came nearer.

To render this, if poſſible, ſtill clearer, let us conſider two ſhips meeting at ſea, the top-maſt of each are the parts firſt diſcovered by both, the hull, &c. being concealed by the convexity of the globe which riſes between them. The ſhips may, in this inſtance, be reſembled to two men, who approach each other on the oppoſite ſides of a hill; their heads will be firſt ſeen, and gradually, as they approach, the body will come entirely in view. From hence is derived a rational method of eſtimating the diſtance of a ſhip, which is in uſe among ſea-faring people, namely, of obſerving *how low they can bring her down*, that is to ſay, the man at the maſt-head fixes his eyes on the veſſel in ſight, and ſlowly deſcends by the ſhrouds, till ſhe becomes no longer viſible. The leſs the diſtance, the lower he may deſcend before ſhe diſappears. If obſervations of this kind be made with a teleſcope, the effect is ſtill more remarkable; as the diſtance increaſes or diminiſhes, the ſhip in ſight will appear to become more and more immerſed, or to riſe gradually out of the water.

This truth is fully evinced by the following conſideration; that ſhips have ſailed round the earth, have gone out to the weſtward, and have come home from the eaſtward; or in other words, the ſhips have kept the ſame courſe, and yet returned from the oppoſite ſide into the harbour whence they firſt ſailed. Now we are certain that this could not be the caſe, if the earth were a plane; for then a perſon, who ſhould ſet out for any one point, and go on ſtrait forward, without ſtopping, would be continually going further from the point from which he ſet out. This argument may be much elucidated, by referring the pupil to a terreſtrial globe, on which he may follow the tracks of an Anſon and a Cook round the world.

Fig. 1 and 2, plate II. are illuſtrations of the foregoing principles. Fig. 1, ſhews that if the earth was a plane, the whole of a ſhip would be ſeen at once, however diſtant from the ſpectator, and that whether he was placed at the top or bottom of a hill. From fig. 2, it appears, that the rotundity of the earth, repreſented by the circle A B C, conceals the lower part of the ſhip d, while the top-maſt is ſtill viſible; and that it is not till the ſhip comes to e, that the whole of it is viſible.

The following remarks evince the ſame truth. Obſerve any ſtar nearer the northern part of the horizon, and if you travel to the ſouth, it will ſeem to dip farther and farther downwards, till by proceeding, it will deſcend entirely out of ſight. In the mean time, the ſtars to the ſouthward of our traveller will ſeem to riſe higher and higher. The contrary appearances would happen, if he went to the northward. This proves that the earth is not a plane ſurface, but a curve in the direction ſouth and north. By an obſervaon nearly ſim ilar to this, the traveller may prove the curvature of the earth, in an eaſt and weſt direction.

The globular figure of the earth may be alſo inferred from the operation of *levelling*, or the art of conveying water from one place to another; for in this proceſs, it is found neceſſary to make an allowance between the true and apparent level; or in other words, for the figure of the earth. For the true level is not a ſtrait line, but a curve which falls below the ſtrait line about eight inches in a mile, four times eight in two miles, nine times eight in three miles, ſixteen times eight in four miles, always increaſing as the ſquare of the diſtance.

What the earth loſes of it's ſphericity by mountains and vallies, is very inconſiderable; the higheſt eminence bearing ſo little proportion to it's bulk, as to be ſcarcely equivalent to the minuteſt protuberance on the ſurface of a lemon.

It is proper, however, to acquaint the young pupil, that though we call our earth a globe, and that when ſpeaking in general terms, it may be conſidered as ſuch; yet in the ſtrictneſs of truth, it muſt be obſerved, that it is not exactly and perfectly a ſphere, *but a ſpheriod, flattened a little towards the poles, and ſwelling at the equator;* the equatorial diameter being about thirty-four miles longer than the diameter from pole to pole. This difference bears, therefore, too ſmall a proportion to the diameter, to be repreſented on globes. M. Caſſini, from

Picart's meafure of a degree, afferted, that the earth was an oblong or prolate fpheriod, flattened at the equator, and protuberant at the poles ; while Newton and Huygens, from a confideration of the known laws and the diurnal motion of the earth, concluded that the figure of the earth was that of an oblate fpheroid, flattened at the poles, protuberant at the equator. To decide this important queftion, Louis XIV. ordered two degrees of the meridian to be meafured, one under the equator, the other as near the pole as poffible. For this purpofe, the Royal Academy of Sciences fent Meff. Maupertuis, Clairault, Camus, and Le Monnier, to Lapland : they fet out from France in 1735, and returned in the fpring of the year 1736, having fatisfactorily accomplifhed the purpofe for which they were fent. Meff. Godin, Condamine, and Bouguer, were fent on the fouthern expedition : to thefe the King of Spain joined Don George Juan, and Don Anthony de Ulloa, who left Europe in the year 1735, and after encountering innumerable hardfhips and difficulties, returned to Europe in different times, and by different ways, in 1744, 1745, 1746. The refult of this arduous tafk was a complete confirmation of Newton's theoretical inveftigation. The difference between the equatorial and polar dimenfions, when compared with the earth's femidiameter, is but an inconfiderable quantity, amounting in the whole to an elevation of little more than 16½ of 3970; that is, to less than a 240th part of the distance from the surface of the earth to the center. If a meridional section of such a spheroid were laid down upon paper, the eye would not distinguish it from a perfect circle.

Of the Diurnal Motion of the Earth.

Though it is this motion which gives us the grateful vicissitudes of day and night, adjusted to the times of labour and rest; yet young people generally find some difficulty in conceiving that the earth moves; the more so, because, in order to allow it, they must give up, in a great measure, the evidence of their exterior senses, of which the impressions are at their age exceeding strong and lively. It will, therefore, be necessary for the tutor to prove to them, that they can by no means infer that the earth is at rest, because it appears so, and convince them by a variety of *facts*, that reason was given to correct the *fallacies of the senses*.

To this end we shall here point out some instances, where apparent motion is produced in a body at rest, by the real motion of the spectator. Let us suppose a man in a ship to be carried along by a brisk gale, in a direction parallel to a shore, at no great distance from him; while he keeps his eye on the deck, the mast, the ſails, or any thing about the ſhip, that is to ſay, while he ſees nothing but ſome part of the veſſel on board of which he is, and conſequently every part of which moves with him, he will not perceive that the ſhip moves at all. Let him, after this, look to the ſhore, and he will ſee the houſes, trees, and hills, run from him in a direction contrary to the motion of the veſſel; and ſuppoſing him to have received no previous information on the ſubject, he might naturally conclude, that the apparent motion of theſe bodies was real.

In a ſimilar ſituation to this, we may conceive the inhabitants of the earth; who, in early times, knew nothing of the true ſtructure or laws of the univerſe, ſaw the ſun, the ſtars, and the planets, riſe and ſet, and perform an apparent revolution about the earth. They had no idea of the motion of the earth, and therefore all this appearance ſeemed reality. But as it is highly reaſonable to ſuppoſe, that as ſoon as the ſlighteſt hint ſhould be given to the man, of the motion of the veſſel, he would begin to form a new opinion, and conceive it to be more rational, that ſo ſmall a thing as the ſhip ſhould move, rather than all that part of the earth which was open to his view; ſo, in the ſame manner, no ſooner was an idea formed of the vaſt extent and greatneſs of the univerſe, with refpect to this earth, than mankind began to conceive it would be more rational that the earth fhould move, than the whole fabric of the heavens.

By another familiar inftance it will be eafy to fhew the young pupil, that as the eye does not perceive its own motion, it always judges from appearances. Let a perfon go into a common windmill, and defire the miller to turn the mill round, while he is fitting within it with his eyes fixed on the upright poft in the center thereof; this poft, though at reft, will appear to him to turn round with confiderable velocity, the real motion of the mill being the caufe of the apparent motion of the fwivel poft. Sea-faring people are furnifhed with various inftances to illuftrate this fubject; thofe who are bufy in the hold of a fhip at anchor, cannot by any perception determine whether the fhip has fwung round or not by the turn of the tide. When a fhip firft gets under-way with a light breeze, fhe may be going at a good rate before thofe who are between decks can perceive it. Having thus obviated the objections which arife from the teftimony of the fenfes, we may now proceed to confider the arguments which tend more directly to prove the motion of the earth.

All the celeftial motions will, on this fuppoſition, be incomparably more ſimple and moderate.

This opinion is much more agreeable to our notions of final cauſes, and our knowledge of the œconomy of nature; for if the earth be at reſt, and the ſtars, &c. move round it once in 24 hours, their velocity muſt be immenſe; and it is certainly more agreeable to reaſon, that one ſingle body, and that one of the ſmalleſt, ſhould revolve on its own axis in 24 hours, than that the whole univerſe ſhould be carried round it in the ſame time, with inconceivable velocity.

The rotation of the earth round it's axis is analagous to what is obſerved in the ſun, and moſt of the planets; it being highly probable, that the earth, which is itſelf one of the planets, ſhould have the ſame motion as they have, for producing the ſame effect: and it would be as abſurd in us to contend for the motion of the whole heavens round us in 24 hours, rather than allow a diurnal motion to our globe, as it would be for the inhabitants of Jupiter to inſiſt that our globe and the whole heavens, muſt revolve round them in ten hours, that all it's parts might ſucceſſively enjoy the light, rather than grant a diurnal motion to their habitation.

All the phenomena relative to this ſubject, are as as eafily folved on the fuppofition of the earth's motion, as on the contrary hypothefis.

Befides the foregoing confiderations, there are feveral arguments to be deduced from the *higher parts of aftronomy*, which *demonftrably* prove the diurnal motion of the earth.

Before we enter into a further explanation of phenomena, it will be neceffary to define fome of the principal circles of the globe. The reader will comprehend more fully thefe definitions, and attain more accurate ideas of thefe circles, by placing, while he is reading them, a terreftrial globe or armillary fphere before him. It may, however, be neceffary to premife, that we are at liberty to fuppofe as many circles as we pleafe, to be defcribed on the earth ; and the plane of any of thefe to be continued from the earth until it marks a correfponding circle in the concave fphere of the heavens.

Among thefe circles, the *horizon* is the moft frequently named. Properly fpeaking, there are two circles by this name, but diftinguifhed from each other by added epithets, the one being called the *fenfible*, the other the *rational horizon*.

In general terms, the *horizon* may be defined to be an imaginary circle, that feparates the vifible from the invifible part of the heavens.

If a ſpectator ſuppoſes the floor or plane on which he ſtands, to be extended every way, till it reach the ſtarry heavens, this plane is his *ſenſible horizon.*

The *rational horizon* is a circle, whoſe plane is parallel to the former, but paſſing through the center of the earth.

The *rational horizon* divides the concave ſphere of the heavens into two equal parts, or hemiſpheres; the objects that are in the upper hemiſphere will be viſible; ſuch as are in the lower hemiſphere will be inviſible to the ſpectator.

Though the globe of the earth appears ſo large to thoſe who inhabit it, yet it is ſo minute a ſpeck, when compared to the immenſe ſphere of the heavens, that at that diſtance the planes of the rational and ſenſible horizons coincide: or in other words, the diſtance between them in the ſphere of the heavens, is too ſmall for admeaſurement.

To illuſtrate this, let A B C D, fig. 1, plate III. repreſent the earth; z h n o the ſphere of the ſtarry heaven. If an inhabitant of the earth ſtand upon the point A, his ſenſible horizon is *s e*, his rational one *h o*; the diſtance between the planes of theſe two horizons is A F, the ſemidiameter of the earth, which is meaſured in a great circle upon the ſphere of the heaven, by the angle *e* F *o*, or the arc *e o*; this arc in ſo ſmall a circle, *z h n o*, would amount to ſeveral degrees, and conſequently the difference between the ſenſible and rational horizon would be great enough to be meaſured by obſervation. If we repreſent the ſphere of the heaven by a larger circle, the ſemidiameter of the earth A F, meaſured in this circle, will amount to fewer degrees; for the arc E O is leſs than the arc *e o*; and the larger the ſphere of the heaven is, in proportion to the globe of the earth, the leſs ſenſible is the difference between the two horizons. Now as the ſphere of the earth is but a point, when compared to the ſtarry heaven, the difference between the ſenſible and rational horizon will be inſenſible.

From what has been ſaid, it appears that the only diſtinction between the ſenſible and the rational horizon, ariſes from the diſtance of the object we are looking at.

The *ſenſible horizon* is an imaginary circle, which terminates our view, when the objects we are looking at are upon the earth's ſurface.

The *rational horizon* is an imaginary circle, which terminates our view, when the objects we are looking at are as remote as the heavenly bodies.

As the *rational horizon* divides the apparent celeſtial ſphere into two equal hemiſpheres, and ſerves as a boundary, from which to meaſure the elevation or depreſſion of celeſtial objects; thofe in the upper, or vifible hemifphere, are faid to be high, or elevated above the horizon; and thofe in the other hemifphere are called low, or below the horizon.

The earth being a fpherical body, the horizon, or limits of our view, muft change as we change our place; and therefore every place upon the earth has a different horizon. Thus, if a man lives at *a*, fig. 2, plate III. his horizon is G C; if he lives at *b*, his horizon is H D; if at C, it is A E. From hence we obtain another proof of the fphericity of the earth; for if it were flat, all the inhabitants thereof would have the fame horizon.

The point in the heavens, which is directly over the head of a fpectator, is called the *zenith*.

That point which is directly under his feet, is called the *nadir*.

If a man lives at *a*, fig. 2, plate III. his zenith is A, his nadir E; if he lives at *b*, his zenith is B, his nadir F. Confequently the zenith and horizon of an obferver remains fixed in the heavens, fo long as he continues in the fame place; but he no fooner changes his pofition, than the horizon touches the earth in another point, and his zenith anfwers to a different point in the heavens.

The *axis* of the earth is an imaginary line, conceived to be drawn through the center of the earth upon which line its revolutions are made.

The *poles* of the earth are the extremities of it's axis, or thofe two points on it's furface, where it's axis terminate ; one of thefe is called the *north*, and the other the *fouth pole.* The poles of the heavens, or of the world, are thofe two points in the heavens, where the axis of the earth, if produced, would terminate ; fo that the north pole of the heavens is exactly over the north pole of the earth, and the fouth pole of the heavens is directly over the fouth pole of the earth.

The *equator* is an imaginary circle, which is fuppofed to be drawn round the earth's furface, in the middle between the two poles. It divides the earth into two equal parts, one of which is called the *northern,* the other the *fouthern hemifphere.*

If we fuppofe the plane of the earth's equator to be extended all ways, as far as the heavens, it will mark there a circle, that will divide the heavens into two equal parts ; this circle is called fometimes the *equinoctial,* fometimes the *celeftial equator.*

The *meridian* of any place is a circle fuppofed to pafs through that place and the poles of the earth ; we may therefore imagine as many meridians as there are places upon the earth, becaufe any place that is ever fo little to the eaſt or the weſt of another place, has a different meridian.

By the foregoing definition, we ſee that the meridian of any place is immoveably fixed to that place, and carried round along with it by the rotation of the earth. The meridian marks upon the plane of the horizon the north and ſouth points.

The circle which the ſun appears to deſcribe every year, in the concave ſphere of the heavens, is called the *ecliptic*. It is thus denominated, becauſe in all eclipſes the moon is either in or near the plane of it. But as the earth moves round the ſun, in the plane of the ecliptic, it is likewiſe the plane of the earth's orbit.

If we conceive a zone, or belt, about ſixteen degrees broad, in the concave ſphere of the heaven, with the ecliptic paſſing through the middle of it, this zone is called the *zodiac*. The ſtars in the zodiac were divided by the ancients into twelve equal parts or ſigns, to correſpond with the months of the year; and becauſe the number twelve with them was always expreſſive of fulneſs or completion, it is uſed in that ſenſe in ſacred writ. The ſigns are named, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Piſces.

We may imagine as many circles as we

pleafe drawn on a globe, parallel to the equator, and thefe will decreafe in their diameter, as they approach nearer the poles. The *tropics* are two leffer circles of this kind, parallel to the equator, and 23½ degrees diftant from it; one in the northern hemifphere, which is called the *tropic of Cancer;* the other in the fouthern, which is called the *tropic of Capricorn.* If we conceive the planes of thefe circles expanded, till they reach the ftarry heaven, the fun will be feen to move in that circle which correfponds to the tropic of Cancer on the longeft fummer's day, and in that circle which anfwers to the tropic of Capricorn on the fhorteft winter's day.

The polar circles are two leffer circles, conceived to be defcribed at 23½ degrees diftance from each pole.

The axis of the earth is inclined to the plane of the ecliptic, and makes with it an angle of 66½ degrees; therefore the plane of the earth's equator cannot coincide with the plane of the ecliptic, but thefe two planes make with one another an angle of 23½ degrees.

Of the Annual Motion of the Earth.

The foregoing definitions being underftood, we may now proceed in the defcription of the phenomena of our fyftem. It is owing to the induftry of modern aftronomers, that the annual motion of the earth has been fully evinced; for though this motion had been known to, and adopted by many among the ancient philofophers, yet they were not able to give their opinions that degree of probability, which is attainable from modern difcoveries, much lefs the evidence arifing from thofe demonftrative proofs of which we are now in poffeffion. We fhall, therefore, enumerate fome of the reafons which induce aftronomers to believe that *the earth moves round the fun*, and then explain further the nature of this motion, calculated to afford us the ufeful and delightful variety of the feafons, the mutual allay of immoderate heat and cold, as alfo for the fucceffive growth and recruit of vegetation.

The celeftial motions become incomparably more fimple, and free from thofe looped contortions which muft be fuppofed in the other cafe, and which are not only extremely improbable, but incompatible with what we know of motion.

This opinion is alfo more reafonable, on account of the extreme *minutenefs* of the earth, when compared with the immenfe bulk of the fun, Jupiter and Saturn; and there are no known laws of motion, according to which fo grea a body as the ſun can revolve about ſo ſmall a one as the earth.

The *ſun* is the *fountain* of light and heat, which it darts through the whole ſyſtem; it ought, therefore, to be in the center, that it's influence may be regularly diffuſed through the whole heavens, and communicated in juſt gradations to the whole ſyſtem.

When we conſider the *ſun* as the center of the ſyſtem, we find all the bodies moving round it, agreeable to the univerſal laws of gravity; but upon any other conſideration we are left in the dark.

The motion of the earth round the ſun accords with that general harmony, and univerſal law, which all the other moving bodies in the ſyſtem obſerve, namely, *that the ſquares of the periodic times are as the cubes of the diſtances*; but if the ſun moves round the earth, that law is deſtroyed, and the general order of ſymmetry in nature interrupted.

It is inconteſtibly proved by obſervation, a motion having been diſcovered in all the fixed ſtars, which ariſes from a combination of the motion of light with the motion of the earth in it's orbit.

It will be clearly ſhewn in it's place, that *Venus and Mercury move round the ſun* in orbits that are between it and the earth; that the orbit of the earth is ſituated *between* that of

Venus and Mars; and that the orbits of *Mars*, *Jupiter*, &c. are *exterior* to, and include the other three.

OF THE APPARENT MOTION OF THE SUN, ARISING FROM THE EARTH'S ANNUAL MOTION ROUND IT.

As when a perſon ſails along the ſea coaſt, the ſhore, the villages, and other remarkable places on land, appear to change their ſituation, and to paſs by him; ſo it is in the heavens. To a ſpectator upon the earth, as it moves along it's orbit, or ſails as it were through celeſtial ſpace, the ſun, the planets, and the fixed ſtars, appear to change their places.

Apparent change of place is of two ſorts; the one is that of bodies at reſt, the change of whoſe place depends ſolely on that of the ſpectator; the other is that of bodies in motion, whoſe apparent change of place depends as well on their own motion, as on that of the ſpectator.

We ſhall firſt conſider only that apparent change which takes place in thoſe which are at reſt, and which is owing wholly to the motion of the earth, and ſhew that the ſun, when ſeen from the earth, will appear to move in the ſame manner, whether it revolves round the earth, or whether the earth revolves round the ſun. Let us ſuppoſe the *earth at reſt*, without any motion of it's own, and let the *ſun* be ſuppoſed to *revolve round it* in the orbit A B C D, fig. 1, plate IV; and let E F G H be a circle in the concave ſphere of the ſtarry heavens; as the ſun moves in the order of the letters A B C D in it's orbit, it will appear to a ſpectator on the earth to have deſcribed the circle E F G H. When the ſun is at A, it will appear as if it was among the fixed ſtars that are at E; when it is at B, it will appear among the fixed ſtars at F; when at C, among thoſe at G; and when it is at D, it will appear among the fixed ſtars at H. Indeed, the fixed ſtars and the ſun are not ſeen at the ſame time; but we have ſhewn, that we may tell in what part of the heavens the ſun is, or what fixed ſtars it is near, by knowing thoſe which are oppoſite to it, or come to the ſouth at midnight. Therefore, if we find that any ſet of ſtars, as thoſe at H for inſtance, come to the ſouth at midnight, we may be ſure that they are oppoſite to the ſun; and conſequently, if we could ſee the ſtars in that part of the heavens where the ſun is, we ſhould find them to be thoſe at F.

Secondly, let us ſuppoſe that S is the *ſun*, having *no motion* of it's own, that it reſts within the orbit A B C D, in which we ſhall now ſuppoſe the earth to move, in the order of the letters A B C D. Upon this ſuppoſition, when the earth is at A, the ſun will appear in that part of the heavens where the ſtars G are; when the earth is at B, the ſun will appear in that part of the heavens where the ſtars H are; when the earth is at C, the ſun will appear in that part of the heavens where the ſtars E are; and as the earth revolves round the ſun, in the orbit A B C D, the ſun will appear to a ſpectator on the earth to deſcribe the circle G H E F.

Thus whether the *earth be at reſt*, and the ſun revolves in the orbit A B C D; or the *ſun be at reſt*, and the earth revolves in the ſame orbit, a ſpectator on the earth will ſee the ſun deſcribe the ſame circle E F G H, in the concave ſphere of the heavens.

Hence if the plane of the earth's orbit be imagined to be extended to the heavens, it would cut the ſtarry firmament in that very circle, in which a ſpectator in the ſun would ſee the earth revolve every year: while an inhabitant of the earth would obſerve the ſun to go through the ſame circle, and in the ſame ſpace of time, that the ſolar ſpectator would ſee the earth deſcribe it.

The inhabitants of all the other planets will obſerve juſt ſuch motions in the ſun as we do, and for the very ſame reaſons; and the ſun will be ſeen from every planet to deſcribe the ſame circle, and in the ſame ſpace of time, that a ſpectator in the ſun would obſerve the planet to do. For example, an inhabitant of Jupiter would think that the ſun revolved round him, deſcribing a circle in the heavens in the ſpace of twelve years: this circle would not be the ſame with our ecliptic, nor would the ſun appear to paſs through the ſame ſtars which he does to us. On the ſame account, the ſun, ſeen from Saturn, will appear to move in another circle, diſtinct from either of the former; and will not ſeem to finiſh his period in leſs time than thirty years. Now as it is impoſſible that *the ſun can have all theſe motions really in itſelf*, we may ſafely affirm, that none of them are real, but that they are all apparent, and ariſe from the motions of the reſpective planets.

One phenomenon ariſing from the annual motion of the earth, which has already been ſlightly touched upon, may now be more fully explained; for as from this motion, the ſun appears to move from weſt to eaſt in the heavens, if a ſtar riſes or ſets along with the ſun at any time, it will in the courſe of a few days riſe or ſet before it, becauſe the ſun's apparent place in the heavens will be removed to the eaſtward of that ſtar. Hence thoſe ſtars, which at one time of the year ſet with the ſun, and therefore do not appear at all, ſhall at another time of the year riſe when the ſun ſets, and ſhine all the night. And as any one ſtar ſhifts it's place with reſpect to the ſun, and in conſequence of that with reſpect to the hour of the night, ſo do all the reſt. Hence it is that all thoſe ſtars, which at one time of the year appear on any one ſide of the pole ſtar in the evening, ſhall in half a year appear on the contrary ſide thereof.

Of Phenomena occasioned by the annual and diurnal Motions of the Earth.

Firſt, of thoſe that ariſe from the diurnal motion. As the earth is of a ſpherical figure, that part of it, which comes at any time under the confined view of an obſerver, will ſeem to be extended like a plane; and the heavens will appear as a concave ſpherical ſuperfices, divided by the aforeſaid plane into two equal parts,* one of which is viſible, the other concealed from us by the opacity of the earth.

Now the earth, by it's revolution round it's axis, *carries the ſpectator and the aforeſaid plane from weſt to eaſt;* therefore all thoſe bodies to the eaſt, which could not be ſeen becauſe they were below the plane of the horizon, will become viſible, or riſe above it, when, by the rotation of the earth, the horizon ſinks as it were below them. On the other hand, the oppoſite part of the plane, towards the weſt, riſing above the ſtars on that ſide,

* See page 74 of theſe Eſſays.

will hide them from the ſpectator, and they will appear to ſet, or go below the horizon.

As the earth, together with the horizon of the ſpectator, continues moving to the eaſt, and about the ſame axis, all ſuch bodies as are ſeparated from the earth, and which do not partake of that motion, will ſeem to move uniformly in the ſame time, but in an oppoſite direction, that is, from *eaſt to weſt*; excepting the celeſtial poles, which will appear to be at reſt. Therefore, when we ſay, that the whole concave ſphere of the heavens appears to turn round upon the axis of the world, whilſt the earth is performing one rotation round it's own axis, we muſt be underſtood to except the two poles of the world, for theſe do not partake of this apparent motion.

It is, therefore, on account of the revolution of the earth round it's axis, that the ſpectator imagines the whole ſtarry firmament, and every point of the heaven, (excepting the two celeſtial poles) to revolve about the earth from eaſt to weſt every twenty-four hours, each point deſcribing a greater or leſſer circle, as it is more or leſs remote from one of the celeſtial poles.

The earth is made to revolve on it's axis, in order to give alternate *night* and *day* to every part of it's ſurface.

Although every place on the ſurface is

illuminated by all the ſtars which are above the horizon of that place; yet when the *ſun* is above the horizon, his light is ſo ſtrong, that it quite extinguiſhes the faint light of the ſtars, and produces *day*. When the *ſun* goes below the horizon, or more properly, when our horizon gets above the ſun, the ſtars give their light, and we are in that ſtate which is called *night*.

Now as the earth is an opake ſpherical body, at a great diſtance from the ſun, *one half* of it will always be illuminated thereby, while the other half will remain in darkneſs.

The circle which diſtinguiſhes or divides the illuminated face of the earth from the dark ſide, and is the boundary between light and darkneſs, is generally called *the terminator*. A line drawn from the center of the ſun to the center of the earth, is perpendicular to the plane of this circle.

It is plain, that when any given place on the globe firſt gets into the enlightened hemiſphere, the ſun is juſt riſen to that part; when it gets half-way, or to it's greateſt diſtance from the terminator, it is then *noon*; and when it leaves the enlightened hemiſphere, it is then *ſun-ſet*.

Here it will be neceſſary to premiſe a few conſiderations: Firſt, that on account of the immenſe diſtance of the ſun from the earth, the rays which proceed from it may be confidered as *parallel* to each other. Secondly, that *only one-half* of a globe can be illuminated by parallel rays, and therefore *only one half of the earth* will be enlightened by the fun at one time.

Thefe confiderations will be rendered more forcible, by an attentive furvey of fig. 1, plate V; in which S reprefents the fun, from whom we fuppofe parallel rays to flow in all directions. At A, B, C, are reprefented three different pofitions of the globe of the earth, the bright part being that which is *illuminated* by the rays proceeding from the fun, the fhaded part, the portion of the globe which is in darknefs; of courfe the line T T is the terminator, or boundary of light and darknefs.

In the globe at C, the poles coincide with the terminatcr.

In the globe at A, the north pole is in the enlighted portion, and the fouth pole in the dark hemifphere: while in the oppofite globe at B, the fouthern pole is in the illuminated part, and the north pole in obfcurity.

It is evident, that it is day in any given place on the globe, fo long as that place continues in the enlightened hemifphere; but when, by the diurnal rotation of the earth on it's axis, it is carried into the dark hemifphere, it becomes night to that place.

The length of the day and the night depend therefore on the position of the terminator, with respect to the axis of the earth.

If the poles of the earth be situated in the terminator, as at c, every parallel will be divided into two equal parts; and as the uniform motion of the earth causes any given place to describe equal parts of it's parallel in equal times, the day and the night would be equal on every parallel of latitude, that is, all over the globe, except at the poles, where the sun would neither rise nor set, but continue in the horizon.

But if, as at A and B, the axis be not in the plane of the terminator, the terminator will divide the equator into two equal parts, but all the circles parallel to it into unequal parts; those circles that are situated towards the enlightened pole, will have a greater part of their circumference in the enlightened than in the dark hemisphere; while similar parallels towards the other pole will have the greater part of their circumference in the dark hemisphere. Whence it follows, that the first-mentioned parallels will enjoy longer days than nights; and the contrary will happen to the latter, where the days will be the shortest, and the nights the longest; while at the equator, the days will always be of the same length.

Having shewn that the vicissitudes in the length of the days and nights are occaſioned by the poſition of the *terminator* with reſpect to the axis of the earth, I have now only to explain what occaſions theſe various poſitions; which is the more important, as on theſe depend the diverſity in the ſeaſons of the year.

Of the Seasons of the Year.

In conſidering this ſubject, you will find further proofs of that DIVINE WISDOM which pervades all the works of GOD, and ſee, that no other conformation of the ſyſtem could have given ſuch commodious diſtributions of light and heat, or imparted fertility and pleaſure to ſo great a part of the revolving globe.

The changes in the poſition of the terminator are occaſioned, 1. By the *inclination of the earth's axis to the plane of the ecliptic*, or orbit in which it moves. 2. *Becauſe through the whole of it's annual courſe, the axis of the earth preſerves it's poſition, or continues parallel to itſelf;* that is, if a line be conceived as drawn parallel to the axis, while the earth is in any one point of it's orbit, the axis will in every other poſition of the earth be parallel to the ſaid line.

It muſt be evident to you, that the parallelіſm of the axis muſt occaſion conſiderable differences. By a bare inſpection of the globes A, B, fig. 1, plate V, you will ſee that when the earth is in one pofition of it's orbit, the north pole will be turned towards the fun, but in the oppofite part will be turned from him. But the abfence of the fun's light produces a proportionable degree of cold; hence the feafons are, in the northern and fouthern parts of the globe, diftinctly marked by different degrees of heat and cold. It is this annual turning of the poles towards the fun, that occafions the very long days in the northern and fouthern parts. It is owing to the fame caufe, that the fun feems to rife higher in the heavens during fummer than in winter; and this alternate finking and rifing is perceptible over the whole globe.

If the axis of the earth were *perpendicular* to the plane of it's orbit, the equator and the orbit (or ecliptic) would coincide; and as the fun is always in the plane of the ecliptic, it would in this cafe be always over the equator, as in fig. 3, and *the two poles would be in the terminator*, and there would be no diverfity in the days and nights, and but one feafon of the year; but as this is not the cafe, we may fairly infer, that the axis of the earth is not perpendicular to the plane of it's orbit.

But if the earth's axis be *inclined to the plane of the ecliptic*, when the earth is in the fituation reprefented at fig. 1, plate V, the pole N will be towards the fun, and the pole S will be turned from it; but juft the contrary will happen, when the earth, by going half round the ſun, has arrived at the oppoſite point in it's orbit. Hence the ſun will not always be in the equator, but at one time of the year it will appear nearer to one of the poles, and at the oppoſite ſeaſon it will appear nearer to the other. Here then you find a cauſe for the change of the ſeaſons; for when the ſun leaves the equator, and approaches to one of the poles, it will be ſummer on that ſide of the equator, and when the ſun departs from thence, and approaches to the other pole, it will be winter.

Theſe ideas may be ſtrengthened, and a clearer notion obtained of the effect produced by the inclination of the earth's axis, by conſidering fig. 2, plate V, in which the *ellipſis* is ſuppoſed to repreſent the earth's orbit, the eye ſomewhat elevated above the plane thereof. The earth is here repreſented in the firſt point of each of the 12 ſigns of the ecliptic, as marked in the figure with the 12 correſponding months annexed; P the north pole of the globe, P m it's axis, round which the earth performs it's diurnal revolution from weſt to eaſt; this axis is exhibited as parallel to itſelf in every part of the orbit; P C E ſhews the angle of it's inclination, e the pole, e d the axis of the ecliptic, perpendicular to the plane of the orbit.

In *March*, when the earth is in the firſt point of *Libra*, the ſun appears in the oppoſite point of the ecliptic at *Aries*. In *September*, when the earth is in the firſt point of *Aries*, the ſun will be in *Libra*. At theſe times the terminator paſſes through the poles of the world, and divides every parallel into two equal parts, (ſee c, fig. 1,) conſequently the nocturnal and diurnal arches, or the length of day and night, will be equal in all places over the world.

Conceive the earth to have moved from Libra to Capricorn in June, the axis P m preſerving it's paralleliſm by this motion, the north pole will have gradually advanced into the enlightened hemiſphere; ſo that the whole northern polar circle will be therein, while the ſouthern pole is immerged in obſcurity; the northern parts of the world will enjoy long days, while they are ſhort in the ſouthern parts. While *the earth is moving from Libra through Capricorn to Aries*, the north pole remains in the illuminated hemiſphere, and will therefore have ſix months continual day.

But in the other half year, while *the earth is moving from Aries through Cancer to Libra*, the north pole is turned from the ſun, and therefore in darkneſs, but the ſouth pole is in the illuminated hemiſphere. When the earth is at Cancer, the ſun is at Capricorn; at this ſeaſon the nights to us will as much exceed the days, as the days exceeded the nights, when the earth was in the oppoſite point of her orbit.

From the foregoing explanation it is eaſy to perceive, that the inhabitants of the ſouthern hemiſphere have the ſame viciſſitudes with thoſe of the northern, though not at the ſame time, it being winter in one hemiſphere, when it is ſummer in the other.

From what has been ſaid, you muſt have perceived, that during the courſe of the earth through her orbit, there are four days particularly to be remarked; theſe aſtronomers have diſtinguiſhed by the names of the *ſolſtitial* and *equinoctial* days. The ſolſtitial days are thoſe on which the ſun appears moſt to the northward and the ſouthward: the equinoctial days are thoſe on which he appears in the equator, and the days are equal to the nights.

The annual motion of the earth occaſions a daily apparent change in the declination of the ſun. Thus about the 22d of December, when the earth is in Cancer, the ſun will be over the tropic of Capricorn; and conſequently by the earth's rotation on it's axis, the inhabitants of every part of this circle will ſucceſſively have the ſun in their zenith, or in other words, he will be vertical to them that day at noon.

About the 21ſt of March, the earth is at Libra, and the ſun will then appear in Aries; a central ſolar ray will terminate upon the ſurface of the earth, in the equator; and therefore the ſun appears to be carried round in the celeſtial equator, and is ſucceſſively vertical to thoſe who live under that circle.

About the 21ſt of June, when the earth is in Capricorn, a central ſolar ray terminates on the ſurface of the earth, in the northern tropic, and for that day the ſun appears to be carried round in the tropic of Cancer, and is vertical to thoſe who live under that circle. About the 22nd of September, the earth is in Aries, and the ſun in Libra, and the central ſolar ray again terminates at the equator; conſequently the ſun again appears in the celeſtial equator, and is vertical to thoſe who live under it.

We have ſeen, that as the ſun moves in the ecliptic, from the vernal equinox to the tropic of Cancer, it gets to the north of the equator, or it's declination towards our pole increaſes. Therefore, from the vernal equinox, when the days and nights are equal, till the ſun comes to the tropic of Cancer, our days lengthen, and our nights ſhorten; but when the ſun comes to the tropic of Cancer, it is then in it's utmoſt northern limit, and returns in the ecliptic to the equator again. During this return of the ſun, it's declination towards our pole decreaſes, and conſequently the days decreaſe, and the nights increaſe, till the ſun is arrived in the equator again, and is in the autumnal equinoctial point, when the days and nights will again be equal. As the ſun moves from thence towards the tropic of Capricorn, it gets to the ſouth of the equator; or it's declination towards the ſouth pole increaſes. Therefore, at that time of year, our days ſhorten, and our nights lengthen, till the ſun arrives at the tropic of Capricorn; but when the ſun is arrived there, it is then at it's utmoſt ſouthern limit, and returns in the ecliptic to the equator again. During this return, it's diſtance from our pole leſſens, and conſequently the days will lengthen, as the nights will ſhorten, till they become equal, when the ſun is come round to the vernal equinoctial point.

Our ſummer is nearly eight days longer than the winter. By ſummer is meant here the time that paſſes between the vernal and autumnal equinoxes; by winter, the time between the autumnal and vernal equinox. The ecliptic is divided into ſix northern, and ſix ſouthern ſigns, and interſects the equator at the firſt of Aries, and the firſt of Libra. In our ſummer, the ſun's apparent motion is through the ſix northern, and in winter through the ſix ſouthern ſigns; yet the ſun is 186 days, 11 hours, 51 minutes, in paſſing through the ſix firſt; and only 178 days, 17 hours, 58 minutes, in paſſing through the ſix laſt. Their difference, 7 days, 17 hours, 53 minutes, is the length of time by which our ſummer exceeds the winter.

In fig. 1, plate VI, A B C D repreſents the earth's orbit; S the ſun in one of its foci; when the earth is at B, the ſun appears at H, in the firſt point of Aries; and whilſt the earth moves from B through C to D, the ſun appears to run through the ſix northern ſigns, from ♈ through ♋ to ♎ at F. When the earth is at D, the ſun appears at F, in the firſt point of Libra; and as the earth moves from D through A to B, the ſun appears to move through the ſix ſouthern ſigns, from ♎ through ♑ to Aries at H.

Hence the line F H, drawn from the firſt point of Aries through the ſun at S, to the firſt point of ♎, divides the ecliptic into two equal parts; but the ſame line divides the earth's elliptical orbit into two unequal parts. The greater part B C D is that which the earth deſcribes in the ſummer, while the ſun appears in the northern ſigns. The leſſer part is D A B, which the earth deſcribes in winter, while the ſun appears in the ſouthern ſigns. C, the earth's aphelion, where it moves ſloweſt, is in the greater part; A, it's perihelion, is in the leſſer part, where the ſun moves faſteſt.

There are, therefore two reaſons why our ſummer is longer than our winter; firſt, becauſe the ſun continues in the northern ſigns, while the earth is deſcribing the greater part of it's orbit; and fecondly, becaufe the fun's apparent motion is flower while it appears in the northern figns, than whilft it appears in the fouthern ones.

The fun's apparent diameter is greater in our winter than in fummer, becaufe the earth is nearer to the fun when at A in the winter, than it is when at C in the fummer. The fun's apparent diameter, in winter, is 32 minutes, 47 feconds; in fummer, 31 minutes, 40 feconds.

But if the earth is farther from the fun in fummer than in winter, it may be afked, why our winters are fo much colder than our fummers. To this it may be anfwered, that our fummer is hotter than the winter, firft, on account of the greater height to which the fun rifes above our horizon in the fummer: fecondly, the greater length of our days. The fun is much higher at noon in fummer than in winter, and confequently, as it's rays in fummer are lefs oblique than in winter, more of them will fall upon the furface of the earth. In the fummer, the days are very long, and the nights very fhort; therefore the earth and air are heated by the fun in the day-time, more than they are cooled in the night; and upon this account, the heat will keep increafing in the fummer, and for the fame reafon will decreafe in winter, when the nights lengthen.

I ſhould exceed the limits of this eſſay, if I were to enquire into the ſeveral concurring cauſes of the temperatures that obtain in various climates; it may be ſufficient, therefore, to obſerve what a remarkable proviſion is made in the world, and the ſeveral parts of it, to keep up a perpetual change in the degrees of heat and cold. Theſe two are antagoniſts, or, as Lord Bacon calls them, *the very hands of nature with which ſhe chiefly worketh*; the one expanding, the other contracting bodies, ſo as to maintain an oſcillatory motion in all their parts; and ſo ſerviceable are theſe changes in the natural world, that they are promoted every year, every hour, every moment. From the oblique poſition of the ecliptic, the earth continually preſents a different face to the ſun, and never receives his rays two days together in the ſame direction. In the day and night, the differences are ſo obvious, that they need not be mentioned, though they are moſt remarkable in thoſe climates, where the ſun at his ſetting makes the greateſt angle with the horizon. Every hour of the day, the heat varies with the ſun's altitude, is altered by the interpoſition of clouds, and the action of winds; and there is little room to doubt, but what the various changes that thus take place, concur in producing many of the ſmaller and greater phenomena of nature.

Be this however as it may, it is certain that the various irregularities and intemperature of the elements, which ſeem to deſtroy nature in one ſeaſon, ſerve to revive it in another: the immoderate heats of ſummer, and the exceſſive cold of winter, prepare the beauties of the ſpring, and the rich fruits of autumn. Theſe viciſſitudes, which ſeem to ſuperficial minds the effects of a fortuitous concourſe of irregular cauſes, are regulated according to weight and meaſure, by that SOVEREIGN WISDOM, *who weighs the earth as a grain of ſand, the ſea as a drop of water.*

OF SOLAR AND SIDERIAL TIME.

I have already ſhewn, that the daily motion of the ſun from eaſt to weſt, is not a real, but an apparent one, which is owing to the rotation of the earth round it's axis. Now if the ſun had no other motion but this apparent one, it would ſeem to go once round the earth, in the time of one complete rotation, or in 23 hours, 56 minutes; which is the caſe with any of the fixed ſtars, and is therefore the length of a *ſiderial day*. But the ſun is found to take up a longer time to complete it's apparent revolution; for if it is in the ſouth of any particular place at twelve o'clock at noon to-day, it will not complete an apparent revolution, ſo as to return to the ſouth of that place again, till twelve o'clock at noon on the next day, and confequently the time of this apparent revolution is twenty-four hours.

Let us endeavour to render this fubject clearer, by defining in other words the nature of the folar and fiderial day.

The *folar day* is that fpace of time which intervenes between the fun's departing from any one meridian, and it's return to the fame circle again; which fpace is alfo called a natural day; or it is the time from the noon of one day to the noon of the next.

The *fiderial day* is the fpace of time which happens between the departure of a ftar from, and it's return to the fame meridian again.

I am now to fhew why thefe days differ in length, or why the time, that the fun takes up to complete one revolution, is longer than the time that the earth takes to revolve once upon it's axis.

This difference arifes from the fun's annual motion. For the fun does not continue always in the fame place in the heaven, as the fixed ftars do: but if it is feen at M, fig. 2, pl. IV, one day, near the fixed ftar R, it will have fhifted it's place the next day, and will be near to fome other fixed ftar L. This motion of the fun is from weft to eaft, and one entire revolution is completed in a year. Suppofe, therefore, that the fun, when it is at M, near to the fixed ſtar R, appears in the ſouth of any particular place S; and then imagine the earth to turn once round upon it's axis from weſt to eaſt, or in the direction S T V W, ſo that the place may be returned to the ſame ſituation; after this rotation is completed, the ſtar R will be in the ſouth of the place as before; but the ſun having, in the mean time, moved eaſtwards, and being near to the ſtar L, or to the eaſt of R, will not be in the ſouth of the place S, but to the eaſtward of it: upon this account, the place S muſt move on a little farther, and muſt come to T before it will be even with the ſun again, or before the ſun will appear exactly in the ſouth.

This may be illuſtrated by an inſtance. The two hands of a watch are cloſe together, or even with one another at twelve; they both turn round the ſame way, but the minute hand turns round in a ſhorter time than the hour hand; when the minute hand has completed one rotation, and is come round to twelve, the hour hand will be before it, or will be at one; ſo that the minute hand muſt move more than once round, in order to overtake the hour hand, and be even with it again.

As this ſubject is of ſome importance, we ſhall endeavour to render it more clear, by placing it in a different point of view: the more ſo, and it may accuſtom the young pupil to reaſon on both hypotheſes, namely, the motion of the ſun, and that of the earth.

The diameter of the earth's orbit is but a phyſical point in proportion to the diſtance of the ſtars; for which reaſon, and the earth's uniform motion of it's axis, any given meridian will revolve from any ſtar to the ſame ſtar again, in every abſolute turn of the earth upon it's axis, without the leaſt perceptible difference of time being ſhewn by a clock which goes exactly true.

If the earth had only a diurnal, without an annual motion, any given meridian would revolve from the ſun to the ſun again, in the ſame quantity of time as from any ſtar to the ſame ſtar again; becauſe the ſun would never change his place with reſpect to the ſtars. But as the earth advances almoſt a degree eaſtward in it's orbit, in the time that it turns eaſtward round it's axis, whatever ſtar paſſes over the meridian on any day with the ſun, will paſs over the ſame meridian on the next day, when the ſun is almoſt a degree ſhort of it, that is, 3 min. 56 ſeconds ſooner. If the year contained only 360 days, the ſun's apparent place, ſo far as his motion is equable, would change a degree every day, and then the ſiderial days would be juſt four minutes ſhorter than the ſolar.

Let A B C D E F G H, fig. 3, plate IV, be the earth's orbit, in which it goes round the ſun every year, according to the order of the letters, that is, from weſt to eaſt, and turns round it's axis the ſame way, from the ſun to the ſun again in every twenty-four hours. Let S be the ſun, and R a fixed ſtar, at ſuch an immenſe diſtance, that the diameter G C of the earth's orbit bears no ſenſible proportion to that diſtance; N m n the earth in different points of it's orbit. Let N m be any particular meridian of the earth, and N a given point, or place, lying under that meridian.

When the earth is at A, the ſun S hides the ſtar R, which would always be hid if the earth never moved from A; and conſequently as the earth turns round it's axis, the point N would always come round to the ſun and the ſtar at the ſame time.

But when the earth has advanced through an eighth part of it's orbit, or from A to B, it's motion round it's axis will bring the point N an eighth part of a day, or three hours, ſooner to the ſtar than to the ſun. For the ſtar will come to the meridian in the ſame time as though the earth had continued in it's former ſituation at A, but the point N muſt revolve from N to N, before it can have the ſun upon it's meridian. The arc N n being therefore the ſame part of a whole circle, as the arc A B, it is plain that any ſtar which comes to the meridian at noon, with the ſun, when the earth is at A, will come to it at nine o'clock in the forenoon, when the earth is at B.

When the earth has paſſed from A to C, one-fourth part of it's orbit, the point N will have the ſtar upon it's meridian, or at ſix in the morning, ſix hours ſooner than it comes round to the ſun; but the point N muſt revolve ſix hours more before it has mid-day by the ſun: for now the angle A S D is a right angle, and ſo is N D n; that is, the earth has advanced 90 degrees on it's axis, to carry the point N from the ſtar to the ſun; for the ſtar always comes to the meridian when N m is parallel to R S A; becauſe D S is but a point in reſpect to R S. When the earth is at D, the ſtar comes to the meridian at three in the morning at E, the earth having gone half round it's orbit; N points to the ſtar at midnight, it being then directly oppoſite to the ſun; and, therefore, by the earth's diurnal motion, the ſtar comes to the meridian twelve hours before the ſun, and then goes on, till at A it comes to the meridian with the ſun again.

Thus it is plain, that one abſolute revolution of the earth on it's axis (which is always completed when any particular ſtar comes to be parallel to it's ſituation at any time of the day before) never brings the ſame meridian round from the ſun, to the ſun again; but that the earth requires as much more than one turn on it's axis, to finiſh a natural day, as it has gone forward in that time, which, at a mean ſtate, is a 365th part of a circle.

From hence we obtain a method of knowing by the ſtars, whether a clock goes true or not. For if through a ſmall hole in a window-ſhutter, or in a thin plate of metal fixed to a window, we obſerve at what time any ſtar diſappears behind a chimney, or corner of a houſe, at a little diſtance; and if the ſame ſtar diſappears the next night, 3 min. 56 ſeconds, ſooner by the clock; and on the ſecond, 7 minutes, 52 ſeconds ſooner; the third night, 11 minutes, 48 ſeconds ſooner, and ſo on every night; it is an infallible ſign that the machine goes true; otherwiſe it does not, and muſt be regulated accordingly. This method may be depended on to nearly half a ſecond.

An Explanation of the Phenomena which arise from the Motion of the Earth, and of the inferior Planets, Mercury and Venus.

It will be neceſſary in this place to define more exactly ſome words which have been ſlightly explained before, and recall the reader's attention to ſome definitions that have been already given; and it is preſumed, that theſe repetitions will not be an object of complaint, becauſe they will anſwer the beneficial purpoſe of grounding the reader more firmly in the knowledge of the ſcience, to which this eſſay is intended as an introduction.

When two planets are ſeen together in the ſame ſign of the zodiac, and equally advanced therein, they are ſaid to be in *conjunction*. But when they are in oppoſite ſigns of the zodiac, they are ſaid to be in *oppoſition*. Thus a planet is ſaid to be in oppoſition to the ſun, when the earth is between the ſun and the planet.

The *elongation* of a planet is it's apparent diſtance from the ſun. When a planet is in conjunction with the ſun, it has no elongation; when in oppoſition, it's elongation is 180 degrees.

The *nodes of a planet's orbit* are thoſe two points where the orbit cuts the plane of the ecliptic. I before obſerved, that the orbits of all the planets are inclined to the plane of the ecliptic, and conſequently croſs this plane. In fig. 3, plate III, A B C D is the plane of the ecliptic; E B F D is the orbit of a planet, in which the points B and D are the two nodes.

The *line of the nodes* is a line B D, ſuppoſed to be drawn through the ſun from one node to the other. The *limits of a planet's orbit* are two points in the middle between the two nodes. The point E is called the greateſt northern limit, F the greateſt ſouthern limit.

The greateſt diſtance of the earth, or of any planet from the ſun, it called it's *aphelion*, or higher apſis; it's leaſt diſtance is called the *perihelion*, or lower apſis.

Thus in fig. 4, plate III, A is the place of the aphelion, P that of the perihelion.

The axis, P A, fig. 4, of any planet's ellipſis is called the *line of the apſides:* the extreme points of it's ſhorteſt diameter T V are the places of it's mean diſtance from the ſun, and S T, or S V, the line of it's *mean diſtance.*

When a planet moves according to the order of the ſigns, it's motion is ſaid to be *direct*, or *in conſequentia;* but when it's motion is contrary to the order of the ſigns, it is ſaid to be *retrograde*, or *in antecedentia.*

The place in the ſtarry heavens that any planet appears in, when ſeen from the center of the earth, is called it's *geocentric place.* The place where it would be ſeen in the celeſtial ſphere, by an obſerver ſuppoſed to be in the ſun, is called it's *heliocentric place.*

Of the Conjunctions and Elongations of the inferior Planets, Venus and Mercury.

There are two different ſituations, in which an inferior planet will appear in conjunction with the ſun; one when the planet is between the ſun and the earth, the other when the ſun is between the earth and the planet. Let A, fig. 2, plate VI, be the earth in it's orbit, E the place of Venus in her orbit E H G, S the ſun, F V P Q R T D an arc in the ſtarry heavens. In this ſituation the ſun and Venus are on the ſame ſide of the earth, and will appear in the ſame point of the heavens, ſo as to be in conjunction. If the earth is at A, and Venus at G, they will alſo appear to be in conjunction.

If the earth is at A, the ſun at S, the planet at E, nearer to the earth than the ſun, it is called it's *inferior conjunction.* But if the earth is at A, and the planet at G, farther from the earth than the ſun, this is called the *ſuperior conjunction* of the planet.

If an inferior planet is at E, the earth at A, and the ſun at S, the elongation is nothing, the planet being then in it's inferior conjunction. As the planet moves from E to y, it's elongation increaſes; for when it is at y, it appears in the line A y P, while the ſun appears in the line

A S Q; fo that P A Q will be it's elongation. When the planet is arrived at x, it appears in the line A x V, which is a tangent to it's orbit; and then it's elongation is V A Q, which is the greateft that can be on that fide the fun; for after this, the elongation decreafes. When the planet is at K, it's elongation is P A Q; when at G, it is nothing, becaufe it is then in it's fuperior conjunction; as the planet moves on from G, it's elongation again increafes; for when it comes to C, it appears in the line A C R, and it's elongation is R A Q. When the planet comes to H, a line drawn from the earth through the planet is a tangent to the orbit, and the elongation is T A Q, the greateft it can have when it is on the other fide of the fun; for after this, the elongation again decreafes.

Hence it is clear, that the inferior planets can never appear far from the fun, but muft always accompany it in it's apparent motion through the ecliptic. When we fee either Venus or Mercury, it is either in the evening in the weft, foon after the fun has fet; or in a morning, a little before the fun rifes. Venus is indeed bright enough fometimes to be feen in the day time, but then fhe is never far from the fun. The greateft elongation of Venus is about 40, and of Mercury about 33 degrees.

If the earth is at A, fig. 2, plate VII, when Venus appears in any part of the arc E x G, ſhe is weſtward from the ſun, and therefore riſes before him in the morning, and is called the *morning ſtar*. When ſhe appears any-where in the arc G H E, ſhe is eaſtward from the ſun, and therefore ſets after him; is ſeen in the evening, and is then the *evening ſtar*.

From the apparent motions of the inferior planets, we derive an argument to prove *the falſity of the Ptolemaic ſyſtem*. If the earth was within the orbit of Venus, as the Ptolemaic ſyſtem ſuppoſes, ſhe might be ſometimes on one ſide of the earth, whilſt the ſun is on the oppoſite ſide; or Venus might be ſometimes in oppoſition to the ſun; but Venus is never ſeen in oppoſition. Therefore the earth is on the outſide of the orbit of Venus, and conſequently the Ptolemaic ſyſtem is not true. The ſame is alſo true of Mercury. But this, and ſome other circumſtances relative to the motions of theſe planets, will be better underſtood by a planetarium than by any diagram.

Of the retrograde, direct, and stationary Motions of Venus and Mercury.

It is eaſy to explain theſe motions on the Copernican ſyſtem, it being the natural reſult of the reſpective ſituations and motions of the earth and theſe planets. But on the Ptolemaic ſyſtem they are inexplicable, without calling in the aid of a very complicated hypotheſis.

When the inferior planets are paſſing from their greateſt elongation, on one ſide of the ſun, through their ſuperior conjunction, to their greateſt elongation on the other ſide, their motion, as viewed from the earth, is direct. In order to explain this propoſition, we ſhall firſt ſuppoſe the earth to be at reſt at A, fig. 2, pl. VII; and correct this ſuppoſition afterwards, by ſhewing that the apparent motion of Venus, or Mercury, ſeen from the earth, is the ſame in this reſpect, whether the earth moves in it's orbit, or reſts at A.

The propoſition to be explained is this; that as Venus, for inſtance, moves from x, it's greateſt elongation on one ſide of the ſun, through G it's ſuperior conjunction, to H it's greateſt elongation on the other ſide, it will appear to a ſpectator upon the earth, to move from weſt to eaſt according to the order of the ſigns; that is, it's geocentric motion will be direct.

The planets move round the ſun from weſt to eaſt, and conſequently if there was a ſpectator at the ſun, they would appear to him to move through the zodiac, according to the order of the ſigns; or in other words, the heliocentric motion of Venus is direct. Now if the ſun and the earth A, are both on the ſame ſide of the planet, a ſpectator at the earth is in the ſame ſituation, with reſpect to the planet and it's motion, as if he had been at the ſun: for whilſt the planet is moving from x, through G, to H, a ſpectator either at A or S is on the concave ſide of the planet's orbit; and conſequently the planet will appear to move in the ſame manner from either: but the apparent motion of the planet, when ſeen from the ſun, is *direct*, and conſequently it's motion, when ſeen from the earth, *will alſo be direct*.

For when Venus is at x, it appears to a ſpectator on the earth at A, to be in the line A x V, or is ſeen among the ſtars at V; when Venus has moved to K, it is ſeen among the fixed ſtars at P; when it has moved to G, it is in it's ſuperior conjunction; when it has moved to C, it appears among the fixed ſtars at R; and when it is come to K, it appears among the fixed ſtars at T. Thus whilſt Venus has moved in it's orbit from x, it's greateſt elongation on one ſide of the ſun, through G it's ſuperior conjunction, to H it's greateſt elongation on the other ſide, it appears to have deſcribed the arc V P Q R T in the concave ſphere of the heavens; but the letters x K G C H lie from weſt to eaſt, becauſe they lie in the ſame direction that the planet moves round the ſun; and the letters V P Q R T lie in the ſame direction with x K G C H. Therefore, as the planet ſeems to a ſpectator on the earth, to deſcribe the arc V P Q R T, it's apparent motion, ſeen from the earth, is *direct*, or from weſt to eaſt.

The *ſecond* propoſition is this; that while the inferior planets move from their greateſt elongation on one ſide of the ſun, through their inferior conjunction, to their greateſt elongation on the other ſide, their *geocentric motion is retrograde.*

In other words, whilſt Venus is moving from it's greateſt elongation H, plate VII, fig. 3, through it's inferior conjunction E, to it's other greateſt elongation x, it appears to a ſpectator upon the earth at A, to move backwards, or from eaſt to weſt, contrary to the order of the ſigns.

A ſpectator at the ſun is on the *concave* ſide of the planet's orbit, viewing it from within ſide. But whilſt Venus is moving from it's greateſt elongation H on one ſide, through E it's inferior conjunction, to x it's greateſt elongation on the other ſide, a ſpectator upon the earth is on the *convex* ſide of it's orbit, viewing it from without.

Therefore, if a ſpectator at the ſun S would ſee the planet move one way, a ſpectator at the earth A will ſee it move the contrary way; or the geocentric motion will be contrary to it's heliocentric motion, and therefore retrograde; for as ſeen from the ſun, it's motion is always direct.

That two ſpectators, one at the earth, the other at the ſun, as they are on contrary ſides of the arc H E x, will ſee the planet apparently move contrary ways, may be rendered more plain by the following familiar conſideration. If two men ſtand with their faces towards each other, and a ball is rolled along upon the ground, this ball will move from the right hand of one of the men towards his left, and from the left hand of the other towards his right. In like manner, if one man is at the earth A, and the other at the ſun S, then whilſt the planet is deſcribing the arc H e x which is between them, it will appear to move from the right hand of the man at S towards his left, and from the left hand of the man at A towards his right.

Whilſt the motion of Venus is direct, or while it is deſcribing the arc x G H, it appears to move from V to T, among the fixed ſtars. But after it has been carried in it's orbit from H to Q, it appears in the line A z R, and is ſeen among the fixed ſtars at R. When it comes to E, it appears at Q; and when at y, it's apparent place in the heavens is at P. Thus as the planet paſſes from it's greateſt elongation H on one ſide of the ſun, through it's inferior junction E, to it's greateſt elongation x on the other ſide, *it apparently runs back* from T to V, or it's motion is *retrograde*.

Our *third* propoſition is, that Venus is *ſtationary*, or has no apparent motion for ſome time, when it is at it's greateſt elongation; that is, when it is at H or x, and it's apparent place is either at T or V.

When either of the inferior planets, Venus for inſtance, is at it's greateſt elongation H or x, a line drawn from the earth through the planet, as A H T, or A x V, is a tangent to the orbit. Now though a right line touches a circle but in one point, yet ſome part of the circle greater than a point is ſo near to the tangent, as not to be diſtinguiſhed from it. Thus the arc b d ſo nearly coincides with the tangent A H T, that a ſpectator's eye placed at A, could not diſtinguiſh the tangent from this part of the curve. Conſequently, while the planet is deſcribing this arc, no other change will be made in it's geocentric place, than if it was to move in the tangent.

But the geocentric place of the planet would not be altered, if the planet was to move in the tangent. For if it was to move from T towards A, or from A to V, the apparent place of it in the heavens would in one caſe be at T, in the other caſe at V. Therefore, while the planet is at it's greateſt elongation, and is defcribing a fmall arc in it's orbit, that nearly coincides with the tangent, it's geocentric place does not alter, *but it appears to continue for fome time in the fame part of the heavens*, or is *ftationary*.

I have hitherto fuppofed the earth to be at reft, and upon that fuppofition have explained the progrefs and regrefs, the conjunctions and ftations of the inferior planets. If this fuppofition was true, V T, or the arc which the planet at any time defcribes in it's progrefs, and T V, the arc which it defcribes in it's regrefs, would always be in the fame part of the heavens. The planet, when in conjunction, would always appear at Q among the fame fixed ftars; and at it's elongation, or when it is ftationary, it would always appear among the fame fixed ftars at T on one fide of the fun, and at V on the other fide.

But this fuppofition is not true; for the earth revolves in it's orbit A B O round the fun. Now if the earth is at A, at the time of either conjunction, the planet at this conjunction would appear among the fixed ftars at Q, and the arcs of the greateft elongation Q V and Q T, would be on each fide of thofe ftars. But if the earth is at B, at the time of either of the conjunctions, then at the time of this conjunction, the planet will appear in the line B S T, and be feen among the fixed ftars at T, and the arcs of the greateſt elongation will be on each ſide of theſe ſtars; that is, the conjunctions and elongations will happen in a different part of the heavens, when the earth is at B, from what they happen when the earth is at A. In other reſpects, the foregoing phenomena will be much the ſame, notwithſtanding the motion of the earth, only the planet will be more direct in the fartheſt part of the orbit, and leſs retrograde in the neareſt.

The inferior planets always appear very near the ſun; but by the motion of the earth in it's orbit, the ſun appears in different parts of the heavens, in different times of the year. Therefore the inferior planets, as they are always very near the ſun, will alſo appear in different parts of the heavens, at different times of the year. And conſequently their conjunctions and greateſt elongations will ſometimes happen when they are in one part of the heavens, and ſometimes when they are in another part. Venus, ſeen from the earth, will appear to vibrate in an arc V T, half of which is on one ſide of the ſun's apparent place, and half on the other ſide.

When an inferior planet, viewed from a ſuperior, moves apparently retrograde, the ſuperior planet has alſo an apparently retrograde motion.

When a ſuperior planet, viewed from an

inferior, appears ſtationary, the inferior planet viewed at the ſame time from the ſuperior, is alſo ſtationary.

Of the Phases of Venus.

That the planets are all opake or dark bodies, and conſequently ſhine only by the light they receive from the ſun, is plain, becauſe they are not viſible when they are in ſuch parts of their orbits as are between the ſun and earth, that is, when their illuminated ſide is turned from us.

The ſun enlightens only half a planet at once; the illuminated hemiſphere is always that which is turned towards the ſun, the other hemiſphere of the planet is dark. To ſpeak with accuracy, the ſun being larger than any of the planets, will illuminate rather more than half; but this difference, on account of the great diſtance of the ſun from any of the planets, is ſo ſmall, that it's light may be conſidered as coming to them in lines phyſically parallel.

Like other opake bodies, they caſt a ſhadow behind them, which is always oppoſite to the ſun. The line in the planet's body, which diſtinguiſhes the lucid from the obſcure part, appears ſometimes ſtrait, ſometimes crooked. The convex part of the curve is ſometimes towards the ſplendid, and the concave towards that which is obſcure, and vice verſa, according to the ſituation of the eye with reſpect to the planet, and of the ſun which enlightens the planet.

Hence the inferior planets going round the ſun in leſs orbits than our earth does, will ſometimes have more, ſometimes leſs of their illuminated ſide towards us; and as it is the illuminated part only which is viſible to us, Mercury and Venus will, through a good teleſcope, exhibit the ſeveral appearances of the moon, from a fine thin creſcent to the enlightened hemiſphere.

If we view Venus through a teleſcope, when ſhe follows the ſun's rays on the eaſtern ſide, and appears above the horizon after ſunſet, we ſhall ſee her appear nearly round, and but ſmall; ſhe is at that time beyond the ſun, and preſents to us an enlightened hemiſphere. As ſhe departs from the ſun towards the eaſt, ſhe augments in her apparent ſize; and on viewing her through a teleſcope, is ſeen to alter her figure, abating of her apparent roundneſs, and appearing ſucceſſively like the moon, in the different ſtages of her decreaſe. At length, when ſhe is at her greateſt elongation, ſhe is like the moon in her firſt quarter, and appears as ſhe does when from a full, ſhe has decreaſed to a half moon.

After this, as ſhe approaches (in appearance) to the ſun, ſhe appears concave in her illuminated part, as the moon when ſhe forms a creſcent; thus ſhe continues till ſhe is hid entirely in the ſun's rays, and preſents to us her whole dark hemiſphere, as the moon does in her conjunction, no part of the planet being then viſible.

When ſhe departs out of the ſun's rays on the weſtern ſide, we ſee her in the morning, juſt before day-break. It is in this ſituation that Venus is called the morning ſtar, as in the other ſhe is called the evening ſtar. She at this time appears very beautiful, like a fine thin creſcent: juſt a verge of ſilver light is ſeen on her edge. From this period ſhe grows more and more enlightened every day, till ſhe is arrived at her greateſt digreſſion or elongation, when ſhe again appears as a half moon, or as the moon in her firſt quarter; from this time, if continued to be viewed with a teleſcope, ſhe is found to be more and more enlightened, though ſhe is all the while decreaſing in magnitude, and thus continues growing ſmaller and rounder, till ſhe is again hid or loſt in the ſun's rays.

Fig. 1, plate VII, repreſents the orbits of Venus and the earth, with the ſun in the center of them. The planet Venus in drawn in eight different ſituations, with it's illuminated hemifpheres towards the fun. If we fuppofe the earth to be at T, when Venus is at A, her dark hemifphere is towards the earth, and fhe is therefore invifible, except the conjunction happens in her node, for then fhe appears like a dark fpot upon the difk of the fun. When Venus is at B, a little of her enlightened fide is turned towards the earth, and therefore fhe appears fharp-horned; when fhe is at C, half her enlightened hemifphere is turned towards the earth, and fhe appears like an half moon; at D, more than half her enlightened hemifphere is towards us, and fhe appears like the moon about three days before it is full; at E, the whole enlightened hemifphere is towards the earth, Venus is then either behind the fun, or fo very near him, that fhe can hardly be feen; but if fhe could, fhe would appear round, like the full moon. At F fhe is like the moon three days after the full; at G like a half moon again; at H like a crefcent, with the points of the horn turned the contrary way to what they were at B. *All this is equally applicable to Mercury.*

Fig. 2, plate VIII, exhibits the different appearances of Venus, correfponding to her feveral fituations in the foregoing figure; thus when Venus is at A, fig. 1, fhe is quite dark, as at A, fig. 2; when fhe is at B, fig. 1, fhe appears as at B, fig. 2, &c.

The inferior planets do not ſhine brighteſt when they are full; thus Venus does not appear brighteſt in her ſuperior conjunction, though her illuminated hemiſphere be then turned towards us. Her ſplendor is more diminiſhed by her being at a greater diſtance from us, than the conſpicuous part of her illuminated diſk is increaſed. Dr. Halley has ſhewn, that Venus is brighteſt when her elongation from the ſun is but 40°. Mercury is in his greateſt brightneſs, when very near his utmoſt elongation.

Of the superior Planets.

I have already obſerved, that the greateſt elongation of either of the inferior planets is leſs than 90°, or a quarter of a circle; ſo that they are never far from the ſun, but conſtantly attend it. But the ſuperior planets do not always accompany the ſun, as I have ſhewn that the inferior ones do; they are indeed ſometimes in conjunction with it, but then they are alſo ſometimes in oppoſition to, or 180° from it.

Let S, fig. 3, plate VI, be the ſun; A B C D the orbit of any ſuperior planet, Mars, for inſtance; E F G the earth's orbit. If the earth be at E, the ſun at S, and the planet at D, the ſun and the planet will be both on the ſame ſide of the earth ; and conſequently the planet will appear in *conjunction* with the ſun. But as the orbit of the earth is between the ſun and the orbit of the ſuperior planet, it is poſſible for the earth to be between the ſun and the planet, and conſequently for the planet and the ſun to be on oppoſite ſides of the earth, or the planet to be in oppoſition ; thus, if when the earth is at E, Mars be at A, he is then in *oppoſition* to the ſun.

A ſuperior planet is in *quadrature* with the ſun, when it's geocentric place is 90° from the geocentric place of the ſun. If the earth be at E, and Mars at B or C, he is in *quadrature* with the ſun ; for the lines A E, E B, form a right angle, as do alſo the lines E A, E C.

Of the direct, stationary, and retrograde Motion of the superior Planets.

As the earth goes round the ſun in leſs time, and in a leſs orbit than any of the ſuperior planets, it will not be amiſs to ſuppoſe a ſuperior planet to ſtand ſtill in ſome part of it's orbit, while the earth goes once round the ſun in her's, and conſider the appearances the planets would then have, which are theſe : 1. While the earth is in her moſt diſtant ſemicircle, the apparent motion of the planet would be *direct*. 2. While the earth is in her neareſt ſemicircle, the planet would be *retrograde*. 3. While the earth is near the points of contact of a line drawn from the planet, ſo as to be a tangent to the earth's orbit, the planet would be *ſtationary*.

To illuſtrate this, let A B C D E F G H, plate VII, fig. 1, be the orbit of the earth, S the ſun, P Q O V the orbit of Mars, L M N T an arc of the ecliptic. Let us now ſuppoſe the planet Mars to continue at P, while the earth goes round in her orbit, according to the order of the letters A B C, &c. A B C D E F H G may be conſidered as ſo many ſtations, from whence an inhabitant of the earth would view Mars at different times of the year; and if ſtrait lines be drawn from each of theſe ſtations, through Mars at P, and be continued to the ecliptic, they will point out the apparent place of Mars, at theſe different ſtations.

Thus ſuppoſing the earth at A, the planet will be ſeen among the ſtars at L; when the earth is arrived at B, the planet will appear at M; and in the ſame manner when at C D and E, it will be ſeen among the ſtars at N R T; therefore, while the earth moves over the large part of the orbit A B C D E, the planet will have an apparent motion from L to T, and this motion is from *weſt to eaſt*, or the ſame way with the earth; and the planet is ſaid to move *direct*, or according to the order of the ſigns.

When the earth is near to A and E, the point of contact of the tangent to the earth's orbit, the planet will be *ſtationary* for a ſhort ſpace of time.

When the earth moves from E to H, the planet ſeems to return from T to N; but while it moves from H to A, it will appear to move in a contrary direction, and thus be *retrograde* from N to L, where it will again be *ſtationary*: and ſince the part of the orbit which the earth deſcribes in paſſing from A to E, is much greater than the part E H P, though the ſpace T L which the planet deſcribes in direct and retrograde motion is the ſame, the direct motion from L to T muſt be much ſlower than the retrograde motion from T to L.

When the earth is at C, a line drawn from C through S and P to the ecliptic, ſhews that Mars is then in conjunction with the ſun. But when the earth is at H, a line drawn from H through P, and continued to the ecliptic, would terminate in a point oppoſite to S; therefore in this ſituation Mars would be in oppoſition to the ſun. Thus it appears that the motion of Mars is direct when in conjunction, and retrograde when in oppoſition.

The retrograde motions of the ſuperior planets happen oftener, the ſlower their motions are; as the retrograde motions of the inferior planets happen oftener, the ſwifter their angular motions. Becaufe the retrograde motions of the fup-rior planets depend upon the motions of the earth ; but thofe of the inferior on their own angular motion. A fuperior one is retrograde once in each revolution of the earth ; an inferior one in every revolution of it's own.

Other Phenomena of the superior Planets.

The fuperior planets are fometimes nearer the earth than at other times ; they alfo appear larger, or fmaller, according to their different diftances from us. Thus fuppofe the earth to be at C ; if Mars be at P, he is the whole diameter of the earth's orbit nearer to us than if he were at V, and confequently his difk muft appear larger at V than it would be at P. In other places, the diftances of Mars from the earth are intermediate.

The diameter of the earth's orbit bears a greater ratio to the diameter of the orbit of Mars, than it does to the diameter of the orbit of Jupiter ; and a greater to that of Jupiter, than of Saturn ; confequently the difference between the greateft and leaft apparent diameters is greater in Mars than in Jupiter, and greater in Jupiter than in Saturn.

The fuperior, like the inferior planets, do not always appear in the ecliptic, their orbits being inclined alſo to that of the earth; one half is therefore above the ecliptic, the other half below it, nor are they ever ſeen in it but when they are in their nodes.

They alſo move in an ellipſe. They are ſometimes nearer to, and ſometimes further from the earth. Their apparent diameter varies according to the difference in their diſtance.

OF THE SECONDARY PLANETS, OR SATELLITES.

It has been already obſerved, that four of the primary planets, the Earth, Jupiter, Saturn, and the Georgium Sidus, are, in their revolutions round the ſun, attended by ſecondary planets.

As the moon turns round the earth, enlightening our night, by reflecting the light ſhe receives from the ſun, ſo do the other ſatellites enlighten the planets to which they belong, and move round thoſe planets at different periods of time, proportioned to their ſeveral diſtances; and as the moon keeps company with this earth, in it's annual revolution round the ſun, ſo do they ſeverally accompany the planets to which they belong in their ſeveral courſes round that luminary.

I ſhall ſpeak here firſt of the moon, which of all the heavenly bodies, excepting the ſun, is the moſt ſplendid and brilliant, the inſeparable companion and attendant of our earth. In mythology ſhe was conſidered as Luna, in the heavens the radiant planet of the night, upon earth as the chaſte Diana, and as the tremendous Hecate in Hell.

Of the Moon.

If we imagine the plane of the moon's orbit to be extended to the ſphere of the heaven, it would mark therein a great circle, which may be called the moon's apparent orbit; becauſe the moon appears to the inhabitants of the earth to move in that circle, through the twelve ſigns of the zodiac, in a periodical month. This poſition is illuſtrated by the following figure; let E F G H I, fig. 3, plate IX, be the orbit of the earth, S the ſun, a b c d the orbit of the moon, when the earth is at E: let A B C D be a great circle in the ſphere of the heaven, in the ſame plane with the moon's orbit. The moon, by going round her orbit according to the order of letters, appears to an inhabitant of the earth to go round in the great circle A B C D, according to the order of thoſe letters: for when the moon is at a, ſeen from the earth at E, ſhe appears at A; when the moon is got to b, ſhe appears at B; when to c, ſhe will appear at C; when arrived at d, ſhe will appear at D. It is true, when the moon is at b, the viſual line drawn from E, through the moon, terminates in L; as it does in M, when the moon is at d; but the lines L M and D B being parallel, and not farther diſtant from each other than the diſtance of the earth's orbit, are as to ſenſe coincident, their diſtance meaſured in the ſphere of the heaven being inſenſible: for the ſame reaſon, though the earth moves from E to F, in the time that the moon goes round her orbit, ſo that at the end of a periodical month the moon will be at a, and is ſeen from the earth at F, in the line F N; the moon will, notwithſtanding, appear at A, the lines F N and E A being parallel, and as to ſenſe coincident: in like manner, in whatever part of her orbit the earth is, as at H or I, the moon, by going round in her orbit, will appear to an inhabitant of the earth to go round in the great circle A B C D.

The plane of the moon's orbit extended to the heavens, cuts the ecliptic in two oppoſite points.

The two points where the moon's apparent orbit thus cuts the ecliptic, are called the *moon's nodes.*

The point where the moon appears to croſs the ecliptic, as ſhe goes into north latitude, is called the moon's aſcending node, of which this is the character ☊; the point where the moon goes into south latitude is her descending node, and is marked thus ☋; the moon's ascending node is often called the dragon's head; her descending node the dragon's tail.

The line of the moon's node is a line drawn from one node to the other.

The extremities of the line of the nodes are not always directed towards the same points of the ecliptic, but continually shift their places from east to west, or contrary to the order of the signs, performing an entire revolution about the earth, in the space of something less than nineteen years.

The moon appears in the ecliptic only when she is in one of her nodes; in all other parts of her orbit she is either in north or south latitude, sometimes nearer to, sometimes further removed from the ecliptic, according as she happens to be more or less distant from the nodes.

When the place, in which the moon appears to an inhabitant of the earth, is the same with the sun's place, she is said to be in *conjunction*. When the moon's place is opposite to the sun's place, she is said to be in *opposition*. When she is a quarter of a circle distant from the sun, she is said to be in *quadrature*.

Both the conjunction and oppofition of the moon are termed *fyzigies*.

The common lunar month, or the time that paffes between any new moon and the next that follows, is called *a fynodical month*, or *a lunation*. This month contains 29 days, 12 hours, 44 minutes, 3 feconds.

A periodic month is the time the moon takes up to defcribe her orbit; or in other words, the time in which the moon performs one entire revolution about the earth, from any point in the zodiac to the fame again; and contains 27 days, 7 hours, 43 minutes.

If the earth had no revolution round the fun, or the fun had no apparent motion in the ecliptic, the periodical and fynodical month would be the fame; but as this is not the cafe, the moon takes up a longer time to pafs from one conjunction to the next, than to defcribe it's whole orbit; or the time between one new moon and the next, is longer than the moon's periodical time.

The moon revolves round the earth from weft to eaft, and the fun apparently revolves round the earth the fame way. Now at the new moon, or when the fun and moon are in conjunction, they both fet out from the fame place, to move the fame way round the earth; but the moon moves much fafter than the fun, and confequently will overtake it; and when the moon does overtake it, it will be a new moon again. If the ſun had no apparent motion in the eclipitc, the moon would come up to it, or be in conjunction again, after it had gone once round in it's orbit; but as the ſun moves forward in the ecliptic, whilſt the moon is going round, the moon muſt move a little more than once round, before it comes even with the ſun, or before it comes to conjunction. Hence it is that the time between one conjunction and the next in ſucceſſion, is ſomething more than the time the moon takes up to go once round it's orbit; or a ſynodical month is longer than a periodical one.

In fig. 3, plate VIII, let S be the ſun, C F a part of the earth's orbit, M D a diameter o the moon's orbit when the earth is at A, and m d another diameter parallel to the former, when the earth is at B. Whilſt the earth is at A, if the moon be at D, ſhe will be in conjunction; and if the earth was to continue at A, when the moon had gone once round it's orbit, from D through M, ſo as to return to D again, it would again be in conjunction. Therefore, upon the ſuppoſition that the earth has no motion in it's orbit, the periodical and ſynodical months would be equal to one another. But as the earth does not continue at A, it will move forward in it's orbit, during the revolution of the moon from A to B; and as the moon's orbit moves with it, the diameter M D will then be in the poſition m d; therefore, when the moon has deſcribed it's orbit, it will be at d in this diameter m d; but if the moon is at d, and the ſun at S, the moon will not be in conjunction, conſequently the periodical month is completed before the ſynodical. The moon, in order to come to conjunction, when the earth is at B, muſt be at e, in the diameter e f; or beſides going once round it's orbit, it muſt alſo deſcribe the arc d e. The ſynodical month is therefore longer than the periodical, by the time the moon takes up to deſcribe the arc d e.

This may alſo be explained in another manner, by conſidering the apparent motion of the ſun; a view of the ſubject, that may render it more eaſy to ſome young minds than the foregoing. Thus let us ſuppoſe the earth at reſt at E, fig. 4, plate VIII, M the moon in conjunction with the ſun at S, while the moon deſcribes her orbit A B C about the earth at E, let the ſun advance by his apparent annual motion from S to D. It is plain that the moon will not come in conjunction with the ſun again, till, beſides deſcribing her orbit, ſhe hath deſcribed, over and above, the arc M F correſponding to the arc S D.

Of the Phases of the Moon.

As the moon goes round the earth in a much ſmaller orbit than that in which the earth revolves round the ſun, ſometimes more, ſometimes leſs, and ſometimes no part of her enlightened half will be towards us; hence ſhe is inceſſantly varying her appearance; ſometimes ſhe looks full upon us, and her viſage is all luſtre; ſometimes ſhe ſhews only half her enlightened face, ſoon ſhe appears as a radiant creſcent, in a little time all her brightneſs vaniſhes, and ſhe becomes a beamleſs orb.

The full moon, or oppoſition, is that ſtate in which her whole diſk is enlightened, and we ſee it all bright, and of a circular figure. The new moon is when ſhe is in conjunction with the ſun; in this ſtate, the whole ſurface turned towards us is dark, and is therefore inviſible to us.

The firſt quarter of the moon ſhe appears in the form of a ſemicircle, whoſe circumference is turned towards the weſt. At the laſt quarter, ſhe appears again under the form of a ſemicircle, but with the circumference turned towards the eaſt.

Theſe phaſes may be illuſtrated in a very pleaſing manner to the pupil, by expoſing an ivory ball to the ſun, in a variety of poſitions, by which it may prefent a greater or fmaller part of it's illuminated furface to the obferver. If it be held nearly in oppofition, fo that the eye of the obferver may be almoft immediately between it and the fun, the greateft part of the enlightened fide will be feen; but if it be moved in a circular orbit, towards the fun, the vifible enlightened part will gradually decreafe, and at laft difappear, when the ball is held directly towards the fun. Or to apply the experiment more immediately to our purpofe; if the ball, at any time when the fun and moon are both vifible, be held directly between the eye of the obferver and the moon, that part of the ball on which the fun fhines, will appear exactly of the fame figure as the moon itfelf.

The phafes of the moon, like thofe of Venus, may alfo be illuftrated by a diagram; thus, in fig. 1, plate IX, let S be the fun, T the earth, A B C D E F G H the orbit of the moon. The firft obfervation to be deduced from this figure, is, that the half of the earth and moon, which is towards the fun, is wholly enlightened by it; and the other half, which is turned from it, is totally dark. When the moon is in conjunction with the fun at A, her enlightened hemifphere is turned towards the fun, and the dark one towards the earth; in which cafe we cannot fee her, and it is faid to be new moon. When the moon has moved from A to B, a ſmall portion a b of her enlightened hemiſphere will be turned towards the earth; which portion will appear of the form repreſented at B, fig. 2, plate XI, (a figure which exhibits the phaſes as they appear to us).

As the moon proceeds in her orbit, according to the order of the letters, more and more of her enlightened part is turned towards the earth. When ſhe arrives at C, in which poſition ſhe is ſaid to be in quadrature, one half of that part towards the earth is enlightened, appearing as at C among the phaſes; this appearance is called a half moon. When ſhe comes to D, the greateſt part of that half which is towards us is enlightened; the moon is then ſaid to be gibbous, and of that figure which is ſeen at D, in fig. 2.

When the moon comes to F, ſhe is in oppoſition to the ſun, and conſequently turns all her illuminated ſurface towards the earth, and ſhines with a full face, for which reaſon ſhe is called a full moon. As ſhe paſſes through the other half of her orbit, from E by F G, and H to A again, ſhe puts on the ſame phaſes as before, but in a contrary order or poſition.

As the moon, by reflected light from the ſun, illuminates the earth, ſo the earth does more than repay her kindneſs, in enlightening the ſurface of the moon, by the ſun's reflex light, which ſhe diffuſes more abundantly upon the moon, than the moon does upon us; for the ſurface of the earth is conſiderably greater than that of the moon, and conſequently, if both bodies reflect light in proportion to their ſize, the earth will reflect much more light upon the moon, than it receives from it.

In new moon, the illuminated ſide of the earth is fully turned towards the moon, and the Lunarians will have a full earth, as we, in a ſimilar poſition have a full moon. And from thence ariſes that dim light which is obſerved in the old and new moons, whereby, beſides the bright and ſhining horns, we can perceive the reſt of her body behind them, though but dark and obſcure. Now when the moon comes to be in oppoſition to the ſun, the earth, ſeen from the moon, will appear in conjunction with him, and it's dark ſide will be turned towards the moon, in which poſition the earth will be inviſible to the Lunarians; after this, the earth will appear to them as a creſcent. In a word, the earth exhibits the ſame appearance to the inhabitants of the moon, as the moon does to us.

The moon turns about it's own axis in the ſame time that it moves round the earth; it is on this account that ſhe always preſents nearly the ſame face to us: for by this motion round her axis, ſhe turns juſt ſo much of her ſurface conſtantly towards us, as by her motion about the earth would be turned from us. This motion about her axis is equable and uniform, but that about the earth is unequal and irregular, as being performed in an ellipſis; conſequently the ſame preciſe part of the moon's ſurface can never be ſhewn conſtantly to the earth; which is confirmed by a teleſcope, by which we often obſerve a little ſegment on the eaſtern and weſtern limb, appear and diſappear by turns, as if her body librated to and fro; this phenomenon is called the moon's *libration*. The lunar motions are ſubject to ſeveral other irregularities, which are fully diſcuſſed in the larger works on aſtronomy.

Of the Satellites of Jupiter, Saturn, and the Georgium Sidus.

The exiſtence of all the ſatellites, except the moon, muſt have remained unknown, without the aſſiſtance of the teleſcope. By the aſſiſtance of this inſtrument, Jupiter is found to be attended by four, Saturn by ſeven, and the Georgium Sidus by two.

The ſatellites are diſtinguiſhed according to their places; into firſt, ſecond, &c. the *firſt* being that which is neareſt the planet. They revolve round their reſpective primaries in elliptic orbits, the primary planets being in the focus.

The planes of the orbits of the ſecondary planets produced, interſect the heliocentric orbits of their primaries in two oppoſite points, which are called their nodes.

Again, the planes of the orbits of the ſatellites produced, interſect the ecliptic in two oppoſite points; theſe are called the geocentric nodes of the ſatellites.

The orbits of Jupiter's ſatellites are nearly, but not exactly, in the ſame plane. This plane produced makes an angle of about 3° with Jupiter's orbit. The ſecond deviates a little from the reſt.

The orbits of Saturn's ſatellites, except the 5th, which deviates from the reſt ſeveral degrees, are nearly in the ſame plane. They are nearly parallel to the plane of the equator. The orbit of the 5th ſatellite makes an angle with the orbit of it's primary of 13° 8′.

The ſyſtem of Jupiter and his ſatellites is very large in itſelf; yet, on account of it's immenſe diſtance from us, it appears to occupy but a ſmall ſpace in the ſphere of the ſtarry heavens, and conſequently every ſatellite of Jupiter appears to us always near it's primary, and to have an *oſcillatory motion*, like that of a pendulum, going alternately from it's greateſt digreſſion on one ſide the planet, to it's greateſt on the other, ſometimes in a ſtrait line, at others in an elliptic curve.

When a ſatellite is in it's ſuperior ſemicircle, or that half of it's orbit that is more diſtant from the earth, it's motion appears direct to us; when a ſatellite is in it's inferior ſemicircle, neareſt to the earth, the apparent motion of it is retrograde. Both theſe motions ſeem quickeſt, when the ſatellite is neareſt the center of the primary, and ſlower when they are more diſtant; at the greateſt diſtance they appear ſtationary for a ſhort time.

The ſatellites, and their primaries, mutually eclipſe each other, in the ſame manner in which it has been ſhewn that the earth and the moon do. But there are three caſes, in which the ſatellites diſappear to us.

The one is, when the ſatellite is directly beyond the body of it's primary, with reſpect to the *earth;* this is called an *occultation* of the planet.

Another is, when it is directly behind it's primary, with reſpect to the *ſun*, and ſo falls into it's ſhadow, and ſuffers an eclipſe, as the moon, when the earth is interpoſed between that and the ſun.

The laſt is, when it is interpoſed between the earth and it's primary; for then it cannot be diſtinguiſhed from the primary itſelf.

It is not often that a ſatellite can be diſcovered upon the diſk of Jupiter, even by the beſt teleſcopes, excepting at it's firſt entrance, when, by reaſon of it's being more directly illuminated by the rays of the ſun, than the planet itſelf, it appears like a lucid ſpot upon it; ſometimes however a ſatellite is ſeen paſſing over the diſk like a dark ſpot; this has been attributed to ſpots on the ſurface of the ſatellite, and that the more probably as the ſame ſatellite has been known to paſs over the diſk at one time as a dark ſpot, and at another time to be ſo luminous, as only to be diſtinguiſhed from the planet at it's ingreſs and egreſs. The beginnings and endings of theſe eclipſes are eaſily ſeen by a teleſcope, when the planet is in a proper ſituation; but when it is in conjunction with the ſun, the brightneſs of that luminary renders both the planet and ſatellite inviſible.

By obſerving the eclipſes of Jupiter's ſatellites, it was diſcovered that light is not propagated inſtantaneouſly, though it moves with an incredible velocity; ſo that light reaches from the ſun to us in the ſpace of eleven minutes of time, at more than the rate of 100,000 miles in a ſecond.

The orbits of all the ſatellites of Saturn, except the fifth, are nearly in the ſame plane, which plane makes an angle with that of Saturn's orbit, of about 31°; this inclination is ſo great, that they cannot paſs either acroſs Saturn or behind it, with reſpect to the earth, except when they are very near their nodes, ſo that their eclipſes are not near ſo frequent as thoſe of Jupiter. An occultation of the fourth behind the body of Saturn has been obſerved, and Caſſini once ſaw a ſtar covered by the fourth ſatellite, ſo that for 13 minutes they appeared as one.

Of Eclipses.

Thoſe phenomena, that are termed *eclipſes*, where in former ages beheld with terror and amazement, and looked upon as prodigies that portended calamity and miſery to mankind. Theſe fears, and the erroneous opinions which produced them, had their ſource in the hieroglyphical language of the firſt inhabitants of the earth. We do not, however, imagine that even the moſt ancient of theſe knew any more of the laws and motions of the heavenly bodies, than what could be diſcovered from immediate ſight; or that they knew enough of the lunar ſyſtem to calculate an eclipſe, or even that they ever attempted it.

The word *eclipſe* is derived from the Greek, and ſignifies dereliction, a fainting away, or ſwooning. Now as the moon falls into the ſhadow of the earth, and is deprived of the ſun's enlivening rays, at the time of her greateſt brightneſs, and even appears pale and languid before her obſcuration, lunar eclipſes were called *lunæ labores*, the ſtruggles or labours of the moon; to relieve her from theſe imagined diſtreſſes, ſuperſtition adopted methods as impotent as they were abſurd.

When the moon, by paſſing between us and the ſun, deprived the earth of it's light and heat, the ſun was thought to turn away his face, as if in abhorrence of the crimes of mankind, and to threaten everlaſting night and deſtruction to the world. But thanks to the advancement of ſcience, which, while it has delivered us from the fooliſh fears and idle apprehenſions of the ancients, leaves us in poſſeſſion of their repreſentative knowledge, enables us to explain the appearances on which it was founded, and points out the perverſion and abuſe of it.

Any opake body, that is expoſed to the light of the ſun, will caſt a ſhadow behind it. This ſhadow is a ſpace deprived of light, into which if another body comes, it cannot be ſeen for want of light; the body thus falling within the ſhadow, is ſaid to be *eclipſed*.

The earth and moon being opake bodies, and deriving their light from the ſun, do each of them caſt a ſhadow behind, or towards the hemiſphere oppoſed to the ſun. Now when either the moon or the earth paſſes through the other's ſhadow, it is thereby deprived of illumination from the ſun, and becomes inviſible to a ſpectator on the body from whence the ſhadow comes; and ſuch ſpectator will obſerve an eclipſe of the body which is paſſing through the ſhadow; while a ſpectator on the body which paſſes through the ſhadow, will obſerve an eclipſe of the ſun, being deprived of his light.

Hence there muſt be three bodies concerned in an eclipſe; 1. the luminous body; 2. the opake body that caſts the ſhadow; and, 3. the body involved in the ſhadow.

Of Eclipses of the Moon.

As the earth is an opake body, enlightened by the ſun, it will caſt a ſhadow towards thoſe parts that are oppoſite to the ſun, and the axis of this ſhadow will always be in the plane of the ecliptic, becauſe both the ſun and the earth are always there.

The ſun and the earth are both ſpherical bodies; if they were, therefore, of an equal ſize, the ſhadow of the earth would be cylindrical, as in in fig. 5, plate VIII; and would continue of the ſame breadth at all diſtances from the earth, and would conſequently extend to an infinite diſtance, ſo that Mars, Jupiter, or Saturn, might be eclipſed by it; but as the planets are never eclipſed by the earth, this is not the ſhape of the ſhadow, and conſequently the earth is not equal in ſize to the ſun.

If the ſun were leſs than the earth, the ſhadow would be wider the farther it was from the earth, ſee fig. 6, plate VIII, and would therefore reach to the orbits of Jupiter and Saturn, and eclipſe any of theſe planets when the earth came between the ſun and them; but the earth never eclipſes them, therefore this is not the ſhape of it's ſhadow, and conſequently the ſun is not leſs than the earth.

As we have proved that the earth is neither larger nor equal to the ſun, we may fairly conclude that it is leſs; and that the ſhadow of the earth is a cone, which ends in a point at ſome diſtance from the earth, ſee fig. 7, plate VIII.

The axis of the earth's ſhadow falls always upon that point of the ecliptic that is oppoſite to the ſun's geocentric place; thus if the ſun be in the firſt point of Aries, the axis of the earth's ſhadow will terminate in the firſt point of Libra. It is clear, therefore, *that there can be no eclipſe of the moon but when the earth is interpoſed between it and the ſun, that is, at the time of it's oppoſition, or when it is full;* for unleſs it is oppoſite to the ſun, it never can be in the earth's ſhadow: and if the moon did always move in the plane of the ecliptic, ſhe would every full moon paſs through the body of the ſhadow, and there would be a total eclipſe of the moon.

We have already obſerved, that the moon's orbit is inclined to the plane of the ecliptic, and only coincides with it in two places, which are termed the nodes. It may therefore be full moon * without her being in the plane of the ecliptic; ſhe may be either on the north or the ſouth ſide of it; in either of theſe caſes ſhe will not enter into the ſhadow, but be above it in the one, below it in the other.

To illuſtrate this, let H G, fig. 1, plate X, repreſent the orbit of the moon, E F the plane of the ecliptic, in which the center of the earth's ſhadow always moves, and N the node of the moon's orbit; A B C D four places of the ſhadow of the earth in the ecliptic. When the ſhadow is at A, and the moon at I, there will be no eclipſe: when the full moon is nearer the node, as at K, only part of her globe paſſes through the ſhadow, and that part becoming dark, it is called a *partial eclipſe*; and it is ſaid to be of ſo many *digits* as there are *twelfth parts* of the moon's diameter darkened. When the full moon is at M, ſhe enters

* A planet may be in oppoſition to, or conjunction with the ſun, without being in a right line that paſſes through the ſun and the earth. Aſtronomers term it in conjunction with the ſun, if it be in the ſame part of the zodiac; in oppoſition, if it be in the part of a zodiac, 180° from the ſun.

into the ſhadow C; and paſſing through it, becomes wholly darkened at L, and leaves the ſhadow at O: as the whole body of the moon is here immerſed in the ſhade, this is called a *total eclipſe;* but when the moon's center paſſes through that of the ſhadow, which can only happen when ſhe is at the node at N, it is called a *total and central eclipſe.* There will always be ſuch eclipſes, when the center of the moon and axis of the ſhadow meet in the nodes.

The duration of a central eclipſe is ſo long, as to let the moon go the length of three of it's diameters totally eclipſed, which ſtay in the earth's ſhadow is computed to be about four hours; whereof the moon takes one hour, from its beginning to enter the ſhadow, till quite immerſed therein; two hours more ſhe continues totally dark; and the fourth hour is taken up from her firſt beginning to come out of the ſhadow, till ſhe is quite out of it.

In the beginning of an eclipſe, the moon enters the weſtern part of the ſhadow with the eaſtern part of her limb; and in the end of it, ſhe leaves the eaſtern part of the ſhadow with the weſtern part of her limb. All the intermediate time, from her entrance to her quitting the ſhadow, is reckoned into the eclipſe; but only ſo much into the total immerſion, as paſſes while the moon is altogether obſcured.

From the magnitude of the ſun, the ſize of the earth, their diſtance from each other, the refraction of the atmoſphere, and the diſtance of the moon from the earth, it has been calculated that the ſhadow of the earth terminates in a point, which does not reach ſo far as the moon's orbit. The moon is not, therefore, eclipſed by the ſhadow of the earth alone. The atmoſphere, by refracting ſome of the rays of the ſun, and reflecting others, caſts a ſhadow, though not ſo dark a one as that which ariſes from an opake body: when, therefore, we ſay that the moon is eclipſed, by paſſing into the ſhadow of the earth, it is to be underſtood of the ſhadow of the earth, together with it's atmoſphere. Hence it is that the moon is viſible in eclipſes, the ſhadow caſt by the atmoſphere not being ſo dark as that caſt by the earth. The cone of this ſhadow is larger than the cone of the earth's ſhadow, the baſe thereof broader, the axis longer. There have been eclipſes of the moon, in which the moon has entirely diſappeared: Hevelius mentions one of this kind, which happened in Auguſt 1647, when he was not able to diſtinguiſh the place of the moon, even with a good teleſcope, although the ſky was ſufficiently clear for him to ſee the ſtars of the fifth magnitude.

All opake bodies; when illuminated by the rays of the ſun, caſt a ſhadow from them, which is encompaſſed by a *penumbra*, or thinner ſhadow, which every where ſurrounds the former, growing larger and larger as we recede from the body: in other words, the penumbra is all that ſpace ſurrounding the ſhadow, into which the rays of light can only come from ſome part of that half of the globe of the ſun which is turned towards the planet, all the reſt being intercepted by the intervening body.

Let S, fig. 2, plate X, be the ſun, E the planet, then the penumbral cone is F G H. The nearer any part of the penumbra is to the ſhadow, the leſs light it receives from the ſun; but the further it is, the more it is enlightened; thus the parts of the penumbra near M are illuminated by thoſe rays of light which come from that part of the ſun near to I, all the reſt being intercepted by the planet E. In like manner, the parts about N can only receive the light that comes from the part of the ſun near to L; whereas the parts of the penumbra at P and Q are enlightened in a much greater degree: for the planet intercepts from P only thoſe rays which come from the ſun near L, and hides from Q only a ſmall part of the ſun near I.

The moon paſſes through the penumbra before ſhe enters into the ſhadow of the atmoſphere. This cauſes her gradually to loſe her light, which is not ſenſible at firſt; but as ſhe goes into the darker part of the penumbra, ſhe grows paler. The penumbra, where it is contiguous to the ſhadow, is ſo dark, that it is difficult to diſtinguiſh one from the other. If the atmoſphere be ſerene, every eclipſe of the moon is viſible at the ſame inſtant to all the inhabitants of that ſide of the earth to which ſhe is oppoſite.

The moon in a total eclipſe, generally appears of a duſky reddiſh colour, eſpecially towards the edges; but of a darker towards the middle of the ſhadow.

Of Eclipses of the Sun.

The moon, when in conjunction, if near one of her nodes, will be interpoſed between us and the ſun, and will conſequently hide the ſun, or a part of him, from us, and caſts a ſhadow upon the earth: this is called an *eclipſe of the ſun*; it may be either partial or total.

An eclipſe of any lucid body is a deficiency or diminution of light, which would otherwiſe come from it to our eye, and is cauſed by the interpoſition of ſome opake body.

The eclipſes of the ſun and moon, though expreſſed by the ſame word, are in nature very different; the ſun, in reality, loſes nothing of it's native luſtre in the greateſt eclipſes, but is all the while inceſſantly ſending forth ſtreams of light every way round him, as copiouſly as before. Some of theſe ſtreams are, however, intercepted in their way towards our earth, by the moon coming between the earth and the ſun: and the moon having no light of her own, and receiving none from the ſun on that half of the globe which is towards our eye, muſt appear dark, and make ſo much of the ſun's diſk appear ſo, as is hid from us by her interpoſition.

What is called an eclipſe of the ſun, is therefore, in reality, an eclipſe of the earth, which is deprived of the ſun's light, by the moon's coming between, and caſting a ſhadow upon it. The earth being a globe, only that half of it, which at any time is turned towards the ſun, can be enlightened by him at that time; it is upon ſome part of this enlightened half of the earth, that the moon's ſhadow, or penumbra, falls in a ſolar eclipſe.

The ſun is always in the plane of the ecliptic; but the moon being inclined to this plane, and only coinciding with it at the nodes, it will not cover either the whole or a part of the ſun; or in other words, the ſun will not be eclipſed, unleſs the moon at that time is in or near one of her nodes.

The moon, however, cannot be directly between the ſun and us, unleſs they are both in the ſame part of the heavens; that is, unleſs they are in conjunction. Therefore, the ſun can never be eclipſed but at the new moon, nor even then, unleſs the moon at that time is in or near one of her nodes.

From hence it is eaſy to ſhew, that *the darkneſs of our Saviour's crucifixion was not owing to an eclipſe of the ſun.* For the crucifixion happened at the time of the Jewiſh paſſover, and the paſſover, by the appointment of the law, was to be celebrated at the full moon; the ſun could not, therefore, be eclipſed at the time of the paſſover. An intelligent tutor will find many opportunities of obſerving to his pupil, that nature, and philoſophy, which explains the phenomena of nature, do always agree with divine revelation.

The moon being much ſmaller than the earth, and having a conical ſhadow, becauſe ſhe is leſs than the ſun, can only cover a ſmall part of the earth by her ſhadow; though, as we have obſerved before, the whole body of the moon may be involved in that of the earth. Hence an eclipſe of the ſun is viſible but to a few inhabitants of the earth; whereas an eclipſe of the moon may be ſeen by all thoſe that are on that hemiſphere which is turned towards it. In other words, as the moon can never totally eclipſe the earth, there will be many parts of the globe that will ſuffer no eclipſe, though the ſun be above their horizon.

An eclipſe of the ſun always begins on the weſtern, and ends on the eaſtern ſide ; becauſe the moon moving in her orbit from weſt to eaſt, neceſſarily firſt arrives at and touches the ſun's weſtern limb, and goes off at the eaſtern.

It is not neceſſary, in order to conſtitute a *central* eclipſe of the ſun, that the moon ſhould be exactly in the line of the nodes, at the time of it's conjunction ; for it is ſufficient to denominate an eclipſe of the ſun *central*, that the center of the moon be directly between the center of the ſun, and the eye of the ſpectator ; for to him, the ſun is then centrally eclipſed. But as the ſhadow of the moon can cover but a ſmall portion of the earth, it is obvious this may happen when the moon is not in one of her nodes. Further, the ſun may be eclipſed centrally, totally, partially, and not at all, at the ſame time.

A total eclipſe of the ſun is a very curious ſpectacle : Clavius ſays that, in that which he obſerved in Portugal, in 1650, the obſcurity was greater, or more ſenſible than that of the night : the largeſt ſtars made their appearance for about a minute or two, and the birds were ſo terrified, that they fell to the ground.

Thus in fig. 3, plate X, let A B C be the ſun, M N the moon, h l g part of the cone of the moon's ſhadow, f d the penumbra of the moon : from this figure it is eaſy to perceive,

1. That thoſe parts of the earth that are

within the circle reprefented by g h, are cover-ed by the fhadow of the moon, fo that no rays can come from any part of the fun into that circle, on account of the interpofition of the moon.

2. In thofe parts of the earth where the pe-numbra falls, only part of the fun is vifible; thus between d and g, the parts of the fun near C cannot be feen, the rays coming from thence towards d or g being intercepted by the moon; whereas at the fame time, the parts between f and h are illuminated by rays coming from C, but are deprived by the moon of fuch as come from A.

3. The nearer any part of the earth, with-in the penumbra, is to the fhadow of the moon, as in places near g, l, or h, the lefs portion of the fun is vifible to it's inhabitants; the nearer it is to the outfide of the penumbra, as towards d, e, or f, the greater portion of the fun may be feen.

4. Out of the penumbra, the entire difk of the fun is vifible.

Of the Limits of Solar and Lunar Eclipses.

The diftance of the moon in degrees and minutes, above or below the ecliptic line, is called her *latitude*. If fhe be above the ecliptic, ſhe is ſaid to have north; if below it, ſouth latitude.

If the latitude at any time exceed the ſum of the ſemi-diameter of the moon, equal to 16¼ minutes, and the earth's ſhadow equal to 45¾ minutes, the moon at that time cannot be eclipſed; but will either paſs under or over the ſhadow, according as ſhe happens to be above or below the ecliptic line.

The diſtance from the node, either before or after it, correſponding to the above extent, is about 12 degrees, which is conſequently the limit of lunar eclipſes: for when a full moon happens within 12 degrees of the nodes, ſhe will be eclipſed; and the nearer to the nodes, the greater will the eclipſe be.

If at the new moon, the latitude of the moon exceeds the time of the ſemi-diameters of the ſun 16¼ min. and of the moon 16¾ min. we ſhould ſee no eclipſe of the ſun from the center of the earth. But as we view the luminaries from the ſurface, which is much higher, we are obliged to take in the ſemi-diameter of the earth as ſeen from the moon. Then, if the latitude of the moon be greater than the ſum of theſe three numbers, 94¾ minutes, the ſun will not be eclipſed; for the moon will paſs either over or under his diſk, according as ſhe is above or below the ecliptic line. The diſtance from the node on either ſide agreeing to the above mentioned extent, is the 18 degrees, which is the utmoſt limit of ſolar eclipſes; whence it follows, that if the ſun and moon, at the time of new moon, happen to be within 18 degrees of the node, the ſun will be eclipſed.

Of the Period of Eclipses.

If the places of the moon's nodes were fixed, eclipſes would always happen nearly at the ſame time of the year; but as they have a motion of about 3 min. 11 ſec. every day backwards, or contrary to the order of the ſigns, the ſucceeding eclipſe muſt recede likewiſe; and in one revolution of the nodes, which is completed in 18 years, 224 days, 3 hours, they will revolve in a retrograde manner through the year, and return to the ſame place again.

But there is a more correct period, called the Chaldean Saros, which is 18 years, 11 days, 7 hours, 43 min. for in that time the ſun and moon advance juſt as far beyond a complete direct revolution in the ecliptic, as the nodes want of completing their retrograde one: conſequently, as the ſun and moon meet the nodes at the end of that period, the ſame ſolar and lunar aſpects, which happened 18 years, 11 days, 7 hours, 43 min. ago, will return, and produce eclipſes of both luminaries, for many ages, the ſame as before.

Of ancient aſtronomical obſervations much has been ſaid, with very little foundation, by many modern writers: the oldeſt eclipſes of the moon that Hipparchus could make any uſe of, went no higher than the year before Chriſt 721, Whatever obſervations, therefore, the Chaldeans had before this, were probably very rude and imperfect.*

Of Parallax and Refraction.

Aſtronomy is ſubject to many difficulties, beſides thoſe which are obvious to every eye. When we look at any ſtar in the heavens, we do not ſee it in it's real place; the rays coming from it, when they paſs out of the purer etherial medium, into our coarſer and more denſe atmoſphere, are *refracted*, or bent in ſuch a manner, as to ſhew the ſtar higher than it really is. Hence we ſee all the ſtars before they riſe, and after they ſet; and never, perhaps, ſee any one in it's true place in the heavens. There is another difference in the apparent ſituation of the heavenly bodies, which ariſes from the ſtations in which an obſerver views them. This difference in ſituation is called the *parallax* of an object.

* Coſtard's Hiſtory of Aſtronomy.

Of Parallax.

The *parallax* of any object is the difference between the places that the object is referred to in the celeſtial ſphere, when ſeen at the ſame time from two different places within that ſphere. Or, it is the angle under which any two places in the inferior orbits are ſeen from a ſuperior planet, or even the fixed ſtars.

The parallaxes principally uſed by aſtronomers, are thoſe which ariſe from conſidering the object as viewed from the centers of the earth and the ſun, from the ſurface and center of the earth, and from all three compounded.

The difference between the place of a planet, as ſeen from the ſun, and the ſame as ſeen from the earth, is called the parallax of the annual orbit; in other words, the angle at any planet, ſubtended between the ſun and the earth, is called the parallax of the earth's or annual orbit.

The diurnal parallax is the change of the apparent place of a fixed ſtar, or planet, of any celeſtial body, ariſing from it's being viewed on the ſurface, or from the center of the earth.

The annual parallax of all the planets is very conſiderable, but that of the fixed ſtars is imperceptible.

The fixed ſtars have no diurnal parallax, the moon a conſiderable one; that of the planets is greater or leſs, according to their diſtances.

To explain the parallaxes with reſpect to the earth only, let H S W, fig. 2, plate VII, repreſent the earth, T the center thereof, o R G part of the moon's orbit, P r g part of a planet's orbit, Z a A part of the ſtarry heavens. Now to a ſpectator at S, upon the ſurface of the earth, let the moon appear in G, that is, in the ſenſible horizon of S, and it will be referred to A; but if viewed from the center T, it will be referred to the point D, which is it's true place.

The arc A D will be the moon's parallax; the angle S G T the parallactic angle; or the parallax is expreſſed by the angle under which the ſemi-diameter T S of the earth is ſeen from the moon.

If the parallax be conſidered with reſpect to different planets, it will be greater or leſs as thoſe objects are more or leſs diſtant from the earth; thus the parallax A D of G is greater than the parallax a d of g.

If it be conſidered with reſpect to the ſame planet, it is evident that the horizontal parallax (or the parallax when the object is in the horizon) is greateſt of all, and diminiſhes gradually, as the body riſes above the horizon.

until it comes to the zenith, where the parallax vanifhes, or becomes equal to nothing. Thus A D and a d, the horizontal parallaxes of G and g, are greater than a B and a b, the parallaxes of R and r; but the objects O and P, feen from S or T, appears in the fame place Z, or the zenith.

By knowing the parallax of any celeftial object, it's diftance from the center of the earth may be eafily obtained by trigonometry. Thus if the diftance of G from T be fought, in the triangle S T G, S T being known, and the angle S T G determined by obfervation, the fide T G is thence known.

The parallax of the moon may be determined by two perfons obferving her from different ftations at the fame time; fhe being vertical to the one, and horizontal to the other. It is generally concluded to be about 57′.

But the parallax moft wanted, is that of the fun, whereby his abfolute diftance from the earth is known; and hence the abfolute diftances of all the other planets would be alfo known, from the fecond Keplerian law. But the parallax of the fun, or the angle under which the femi-diameter of the earth would appear at that diftance, is fo exceeding fmall, that a miftake of a fecond will caufe an error of feveral millions of miles.

Of Refraction.

As one of the principal objects of aftronomy is to fix the fituation of the feveral heavenly bodies, it is neceffary, as a firft ftep, to underftand the caufes which occafion a falfe appearance of the place of thofe objects, and make us fuppofe them in a different fituation from that which they really have. Among thefe caufes *refraction* is to be reckoned. By this term is meant the bending of the rays of light as they pafs out of one medium into another.

The earth is every where furrounded by an heterogeneous fluid, a mixture of air, vapour, and terreftrial exhalations, that extend to the regions of the fky. The rays of light from the fun, moon, and ftars, in paffing to a fpectator upon earth, come through this medium, and are fo refracted in their paffage through it, that their apparent altitude is greater than their true altitude.

Let A C, fig. 3, plate VII, reprefent the furface of the earth, T it's center, B P a part of the atmofphere, H E K the fphere of the fixed ftars, A F the fenfible horizon, G a planet, G D a ray of light proceeding from the planet to D, where it enters our atmofphere, and is refracted towards the line D T, which is perpendicular to the ſurface of the atmoſphere; and as the upper air is rarer than that near the earth, the ray is continually entering a denſer medium, and is every moment bent towards T, which cauſes it to deſcribe a curve, as D A, and to enter a ſpectator's eye at A, as if it came from E, a point above G. And as an object always appears in that line in which it enters the eye, the planet will appear at E, higher than it's true place, and frequently above the horizon A F, when it's true place is below it, at G.

This refraction is greateſt at the horizon, and decreaſes very faſt as the altitude increaſes, inſomuch that the refraction at the horizon differs from the refraction at a very few degrees above the horizon, by about one third part of the whole quantity. At the horizon, in this climate, it is found to be about 33′. In climates nearer to the equator, where the air is purer, the refraction is leſs; and in the colder climates, nearer to the pole, it increaſes exceedingly, and is a happy proviſion for lengthening the appearance of the light at thoſe regions ſo remote from the ſun. Gaſſendus relates, that ſome Hollanders, who wintered in Nova Zembla, in latitude 75°, were ſurprized with a ſight of the ſun ſeventeen days before they expected him in the horizon. This difference was owing to the refraction of the atmosphere in that latitude. To the same cause, together with the peculiar obliquity of the moon's orbit to the ecliptic, some of these very northern regions are indebted for an uninterrupted light from the moon much more than half the month, and sometimes almost as long as it is capable of affording any light to other parts of the earth.

Through this refraction we are favoured with the sight of the sun about three minutes and a quarter before it rises above the horizon, and also as much every evening after it sets below it, which in one year amounts to more than 40 hours.

It is to this property of refraction that we are also indebted for that enjoyment of light from the sun when he is below the horizon, which produces the morning and evening twilight. The sun's rays, in falling upon the higher part of the atmosphere, are reflected back to our eyes, and form a faint light, which gradually augments till it becomes day. It is owing to this, that the sun illuminates the whole atmosphere at once: deprived of the atmosphere, he would have yielded no light, but when our eyes were directed towards him; and even when he is in meridian splendor, the heavens would have appeared dark, and as full of stars as on a fine winter's night. The rays of light would have come to us in strait lines, the appearance and diſappearance of the ſun would have been inſtantaneous; we ſhould have had a ſudden tranſition from the brighteſt ſun-ſhine to the moſt profound darkneſs, and from thick darkneſs to a blaze of light. Thus by refraction we are prepared gradually for the light of the ſun, the duration of it's light is prolonged, and the ſhades of darkneſs ſoftened.

To it we muſt attribute another curious phenomenon, mentioned by Pliny; for he relates, that the moon had been eclipſed once in the weſt, at the ſame time that the ſun appeared above the horizon in the eaſt. Mæſtlinus, in Kepler, ſpeaks of another inſtance of the ſame kind, which fell under his own obſervation.

Of the Fixed Stars.

No part of the univerſe gives ſuch enlarged ideas of the ſtructure and magnificence of the heavens, as the conſideration of the number, magnitude, and diſtance of the fixed ſtars. We admire indeed, with propriety, the vaſt bulk of our own globe; but when we conſider how much it is ſurpaſſed by moſt of the heavenly bodies, what a point it degenerates into, and how little more even the vaſt orbit in which it revolves would appear, when ſeen from ſome of the fixed ſtars, we begin to conceive more juſt ideas of the extent of the univerſe, and of the boundaries of creation.

The moſt conſpicuous and brighteſt of the fixed ſtars of our horizon is Sirius. The earth, in moving round the ſun, is 190 millions of miles nearer to this ſtar in one part of it's orbit, than in the oppoſite; yet the magnitude of the ſtar does not appear to be in the leaſt altered, or it's diſtance affected by it; ſo that the diſtance of the fixed ſtars is great beyond all computation. The unbounded ſpace appears filled, at proper diſtances, with theſe ſtars; each of which is probably a ſun, with attendant planets rolling round it. In this view, what, and how amazing, is the ſtructure of the univerſe!

Though the fixed ſtars are the only marks by which aſtronomers are enabled to judge of the courſe of the moveable ones, and we have aſſerted their relative poſitions do not vary; yet this aſſertion muſt be confined within ſome limits; for many of them are found to undergo particular changes, and perhaps the whole are liable to ſome peculiar motion, which connects them with the univerſal ſyſtem of created nature. Dr. Herſchel even goes ſo far as to ſuppoſe, that there is not, in ſtrictneſs of ſpeaking, one fixed ſtar in the heavens; but that there is a general motion of all the ſtarry ſyſtems, and confequently of the folar one, among the reft.

There are fome ftars, whofe fituation and place were heretofore known, and marked with precifion, that are no longer to be feen: new ones have alfo been difcovered, that were unknown to the ancients, while numbers feem gradually to vanifh. There are others which are found to have a periodical increafe and decreafe of magnitude; and it is probable that the inftances of thefe changes would have been more numerous, if the ancients had poffeffed the fame accurate means of examining the heavens as are ufed at prefent.

New ftars offer to the mind a phenomenon more furprizing, and lefs explicable, than almoft any other in the fcience of aftronomy. I fhall felect a few inftances of the more remarkable ones, for the inftruction of the young pupil: a confideration of the changes that take place, at fo immenfe a diftance as the ftars are known to be from him, may elevate his mind to confider the immenfity of *his* power, who regulates and governs all thefe wide extended motions; "*who hath meafured the waters in the hollow of his hand, and meted out heaven with a fpan.*"

It was a new ftar difcovered by Hipparchus, the chief of the ancient aftronomers, that induced him to compofe a catalogue of the fixed ſtars, that future obſervers might learn from his labours, whether any of the known ſtars diſappeared, or new ones were produced. The ſame motives engaged the illuſtrious Tycho Brahe to form, with unremitting labour and aſſiduity, another new catalogue of the ſtars.

Of new ſtars, the firſt of which we have a good account, is that which was diſcovered in the conſtellation Caſſiopea, in the month of November of the year 1572, a time when aſtronomy was ſufficiently cultivated, to enable the aſtronomers to give the account with preciſion. It remained viſible about ſixteen months; during this time, it kept it's place in the heavens, without the leaſt variation. It had all the radiance of the fixed ſtars, and twinkled like them; and was in all reſpects like Sirius, excepting that it ſurpaſſed it in brightneſs and magnitude. It appeared larger than Jupiter, who was at that time in his perigee; and was ſcarce leſs bright than Venus.

It was not by degrees that it acquired this diameter, but ſhone forth at once of it's full ſize and brightneſs, as if of inſtantaneous creation. It continued about three weeks in full and entire ſplendor, during which time it might be ſeen even at noon day, by thoſe who had good eyes, and knew where to look for it. Before it had been ſeen a month, it became viſibly ſmaller, and from thence continued diminiſhing in magnitude till March, 1574, when it entirely diſappeared. As it decreaſed in ſize, it varied in colour; at firſt, it's light was white, and extremely bright; it then became yellowiſh, afterwards of a ruddy colour, like Mars; and finiſhed with a pale livid white, reſembling that of Saturn.

In Auguſt 1596, Fabricius obſerved a new ſtar in the neck of the Whale. In 1637, Phocyllides Holwarda, obſerved it again, and not knowing that it had been ſeen before, took it for a new diſcovery: he watched it's place in the heavens, and ſaw it appear again the ſucceeding year, nine months after it's diſappearance. It has been ſince found to be every year very regular in it's period, except that in 1672 it was miſſed by Hevelius, and not ſeen again till 1676. Bullialdus determined the periodical time between this ſtar's appearing in it's greateſt brightneſs, and returning to it again, to be about 333 days; obſerving further, that this ſtar did not appear at once in it's full magnitude and brightneſs, but by degrees arrived at them.

Three changeable, or re-apparent ſtars have been diſcovered in the conſtellation of the Swan; the firſt was ſeen by Janſonius, in 1600; the ſecond was diſcovered in 1670; the third by Kirchius, in 1686.

In the latter end of September, 1604, a new ſtar was diſcovered near the heel of the right foot of Serpentarius. Kepler, in deſcribing it, ſays, that it was preciſely round, without any kind of hair, or tail; that it was exactly like one of the ſtars, except that in the vividneſs of it's luſtre, and the quickneſs of it's ſparkling, it exceeded any thing he had ever ſeen before. It was every moment changing into ſome of the colours of the rainbow, as yellow, orange, purple, and red; though it was generally white, when it was at ſome diſtance from the vapours of the horizon. Thoſe in general who ſaw it, agreed that it was larger than any other fixed ſtar, or even any of the planets, except Venus: it preſerved it's luſtre and ſize for about three weeks; from this time it grew gradually ſmaller. Kepler ſuppoſes that it diſappeared ſome time between October, 1605, and the February following, but on what day is uncertain.

Beſides theſe ſeveral re-apparent ſtars, ſo well characterized and eſtabliſhed by the earlieſt among the modern aſtronomers, there have been many diſcovered ſince, by Caſſini, Maraldi, and others; Mr. Montanere ſpeaks of having obſerved above one hundred changes among the fixed ſtars.

The ſtar Algol, in Meduſa's head, has been obſerved long ſince to appear of different magnitudes, at different times. The period of it has been lately ſettled by J. Goodrick, Eſq. of York. It periodically changes from the firſt to the fourth magnitude; the time employed from one greateſt diminution to the other, was, anno 1783, at a mean 2 days, 20 hours, 49 minutes, 3 ſeconds.

The cauſes of theſe appearances cannot be aſſigned at preſent with any degree of probability; perhaps they have ſome analogy to the ſpots on the ſun, which at ſome times appear in greater numbers than at others, ſome of them bigger than the whole earth; or perhaps they are owing to ſome real motions of the ſtars themſelves.

There are ſeveral ſtars that appear ſingle to the naked eye, which are, on examination with a teleſcope, found to conſiſt of two, three, &c. The number of double ſtars obſerved before the time of Dr. Herſchel, was but ſmall; but this celebrated aſtronomer has noted upwards of four hundred; among theſe, ſome that are double, others that are treble, double double, quadruple, double treble, and multiple; his catalogue gives the comparative ſize of theſe ſtars, their colour as they appeared to him, with ſeveral other very curious particulars.

OF NEBULÆ, AND OF HERSCHEL'S IDEAS RESPECTING THE CONSTRUCTION OF THE UNIVERSE.

Beſides thoſe appearances of the fixed ſtars already noticed, there is another which deſerves particular attention, namely, *the nebulæ*, or *parts of the heavens which appear brighter than the reſt*. The moſt remarkable among theſe is, that large irregular zone or band of whitiſh light which croſſes the ecliptic in Cancer and Capricorn, and is inclined thereto in an angle of about 60 degrees; it is a circle biſecting the celeſtial ſphere, irregular in breadth and brightneſs, and in many places divided into double ſtreams. The principal part runs through the *Eagle*, the *Swan*, *Caſſiopea*, *Perſeus*, and *Auriga*: it continues it's courſe by the head of *Monocerus*, along by the greater *Dog*, through the *Ship*, under the *Centaur's Feet*; till having paſſed the *Altar*, the *Scorpion's Tail*, and the *Bow of Aquarius*, it ends at laſt where it began.

This curious appearance is owing to a multitude of ſmall ſtars, which are too minute to be diſtinguiſhed by the naked eye; yet, blending their light together, form that whiteneſs which occupies ſo large a tract of the heavens. The milky way may be conſidered as a conſtellation of the teleſcopic ſtars ; a ſea of them, of great breadth, and of a whitiſh colour, encompaſſing the whole heavens: even before aſtronomy reaped any benefit from improvements in optics, Democritus conſidered it as formed of cluſters of ſmall ſtars.

Mr. Herſchel's large teleſcope completely reſolved the whitiſh appearance of the milky way into ſtars. Having viewed and guaged this bright zone in all directions, he found it compoſed of ſhining ſtars, whoſe number increaſes and diminiſhes in proportion to it's apparent brightneſs to the naked eye.

The portion of the milky way that he firſt obſerved, was that about the hand and club of Orion. Here he found an aſtoniſhing multitude of ſtars, which he attempted to number. By eſtimating the number contained in the field of his teleſcope at once, and computing, from a mean of theſe, how many might be contained in a given portion of the milky way, in the moſt vacant places, about that part, he found 63 ſtars ; other ſix fields contained 110, 60, 70, 90, 70, and 74 ſtars : a mean of theſe gives 79 for the number of ſtars in each field ; ſo that, allowing 15 minutes for the diameter of his field of view, a belt of fifteen degrees long, and two degrees broad, could not contain leſs than 50,000 ſtars, large enough to be diſtinctly numbered ; beſides which, he fuſpected twice as many more, which could be ſeen only now and then by faint glimpſes, for want of ſufficient light.

In the moſt crouded parts of the milky way, he has had a field of view of 588 ſtars, and theſe continued for many minutes; ſo that in one quarter of an hour's time not leſs than 116,000 ſtars have paſſed through the field of his teleſcope. He endeavours to ſhew, that the powers of his teleſcope are ſuch, that it will not only reach the ſtars at 497 times the diſtance of Sirius, ſo as to diſtinguiſh them, but that it alſo ſhews the united luſtre of the accumulated ſtars that compoſe a milky nebuloſity at a far greater diſtance. From theſe conſiderations, it is highly probable, that as his twenty feet teleſcope does not ſhew ſuch a nebuloſity in the milky way, it goes already far beyond the extent thereof; and therefore a more powerful inſtrument would remove all doubt, by expoſing a milky nebuloſity beyond the ſtratum, which could then no longer be miſtaken for the dark ground of the heavens.

To a ſpectator placed in indefinite ſpace, all very remote objects appear to be equally diſtant from the eye. To judge of the milky way only from phenomena, we muſt of courſe conſider it as a vaſt ring of ſtars ſcattered promiſcuouſly round the celeſtial regions; but a more perfect view of the ſubject will ſhew us, that the appearance, &c. of this beautiful object arise from our eccentric view. Mr. Wright, in his "Original Theory of the Universe, 1750," and Dr. Herschel since, in "The Philosophical Transactions," have shewn, that this appearance may be accounted for, by assuming it's figure as much more extended towards the apparent zone of illumination, than in any other direction.

Suppose, says Dr. Herschel, a number of stars arranged between *two parallel planes* infinitely extended every way, but at a given considerable distance from each other; and calling this a *siderial stratum*, an eye placed somewhere within it, will see all the stars in the directions of the planes *projected into a great circle*, lucid on account of the accumulation of stars; while the rest of the heavens, at the sides, will only seem scattered over with constellations, more or less crowded, according to the distance of the planes, or numbers of the stars contained in the thickness or sides of the stratum.

If the eye be placed *without* the stratum, but at no very great distance, the appearance of the stars within it would form one of the lesser circles of the sphere, which would be more or less contracted, according to the distance of the eye.

He confiders our *fun* as placed in that ftratum of ftars which forms our milky way, and as not far from the place where fome fmaller ftratum branches out from it. Every ftar in the ftratum has it's own galaxy, only with fuch variations, in form and luftre, as may arife from their particular fituations.

According to Dr. Herfchel, the univerfe confifts of *nebulæ*, or immenfe collections of innumerable ftars, each individual of which is a fun, not only equal, but much fuperior to our's: yet none of the celeftial bodies, in our fyftem, are nearer to one another than we are to *Sirius*, who is fuppofed to be 400,000 times further than the fun from us; that is, thirty-eight millions of millions of miles. The extent of the nebulæ is fuch in fome places, that the light of a ftar placed at it's extreme boundary, fuppofing it to fly with the velocity of twelve millions of miles every minute, muft have taken nearly 3000 years to reach us.

Not content with thefe conjectures, our indefatigable aftronomer endeavours to trace the *origin* of nebulous ftars, and gives us hints concerning their *antiquity*. *Suppofing* fome to have a greater air of vigour than others, he attempts to fhew that they are at diftant periods feparated and fubdivided, and even *decay*. Thefe compofitions and decompofitions he pretends to account for, and points out fome that he confiders as having fuftained greater ravages of time than others! It is not here only that even his very conjectures furpafs all human credulity, for you will find him affigning the boundaries of the vaft periods requifite for forming nebulæ, and hazarding conjectures concerning others, as if they were the *labaratories of the univerfe!*

If you are attentive to aftronomical writers, you will foon perceive that much of our knowledge of aftronomy is founded upon conjecture, though dreffed up with all the parade of mathematical demonftration. You will find much of their reafoning weak; and you will often find them arguing in a circle; and this particularly with refpect to the denfities, magnitudes, diftances, and other affections of the planets. Many of their conclufions are deduced from analogy; a fpecies of reafoning that in it's beft form amounts only to probability. Many of their ideas are fupported upon an affumed attractive power, which they modify at pleafure.

Though in a popular work it is impoffible to enter into a difcuffion of thefe points, yet it may be ufeful to fay fomething concerning the value of conjecture, &c. in phyfical fciences. The world has been fo long befooled by hypothefes in all parts of fcience, that it is now neceffary to treat them with contempt. Conjectures and hypothefes are the invention and works of men, and muft therefore bear proportion to the fkill and capacity of the inventor; and will always be very unlike the works of God, which it is the bufinefs of philofophy to difcover.

It is natural for men to judge of things lefs known, by fome fimilitude they obferve, or think they obferve, between them and things more familiar, or better known: in many cafes we have no other way of judging. Analogical reafoning is not therefore to be always rejected; but it ought always to be obferved, that this kind of reafoning can only afford probable evidence, that it may lead into error, and that it varies in the degrees of it's force according to the nature of the truths from which we reafon, according to their greater or lefs extent, and according as the inftances compared are more or lefs fimilar.

Of Comets.

Comets are a kind of ftars appearing at unexpected times in the heavens, and of fingular and various figures, defcending from far diftant parts of the fyftem, with great rapidity, furprizing us with the fingular appearance of a train, or tail; and after a fhort ftay are carried off to diſtant regions, and diſappear.

They were imagined in ancient times to be prodigies hung out by the immediate hand of God in the heavens, and intended to alarm the world. Their nature being now better underſtood, they are no longer terrible: but as there are ſtill many who think them to be heavenly warnings, portents of future events, it may not be improper for the tutor to inform his pupil, that the Architect of the univerſe has framed every part according to divine order, and ſubjected all things to laws and regulations; that he does not hurl at random ſtars and worlds, and diſorder the ſyſtem of the whole glorious frame, to produce falſe apprehenſions of diſtant events, fears without foundation, and without uſe. Religion glories in the teſt of reaſon, of knowledge, and of true wiſdom; it is every way connected with, and is always elucidated by them. From philoſophy we may learn, that the more the works of the Lord are underſtood, the more he muſt be adored; and that his ſuperintendancy over every portion is more clearly evinced, and more fully expreſſed, by their unvaried courſe, than by ten thouſand deviations.

The exiſtence of an univerſal connection between all the parts of nature is now generally allowed. Comets undoubtedly form a part of this great chain; but of the part they occupy, and of the uſes for which they exiſt, we are equally ignorant. It is a portion of ſcience whoſe perfection is reſerved for ſome diſtant day, when theſe bodies, and their vaſt orbits, may, by long and accurate obſervation, be added to the known parts of the ſolar ſyſtem; when aſtronomy will appear as a new ſcience, after all our diſcoveries, great as we at preſent imagine them to be.

The aſtronomy of comets is very imperfect; for but little can be known with certainty where but little can be ſeen. Comets afford few obſervations on which to ground conjecture, and are for the greateſt part of their courſe beyond the reach of human viſion; but that they are not meteors in the air is plain, becauſe they riſe and ſet in the ſame manner as the moon and ſtars. They are called comets from their having a long tail, ſomewhat reſembling the appearance of hair: ſome, however, have appeared without this appendage, as well defined and round as planets. Imperfect as our knowledge is concerning them, *mathematicians* have even ventured to calculate the ſizes of their orbits, which they have made ſo great as to ſurpaſs the ordinary bounds of credulity.

It is generally ſuppoſed that they are planetary bodies, making part of our ſyſtem, revolving round the ſun in extremely long elliptic curves; that as the orbit of a comet is more or leſs eccentric, the diſtance to which they recede from the ſun will be greater or leſs. Very great difference has been found by obſervation in this reſpect; even ſo great, that the ſides of the elliptic orbit in ſome caſes degenerate almoſt into right lines. They are very numerous; 450 are ſuppoſed to belong to our ſolar ſyſtem.

It is ſuppoſed, that thoſe comets, which go to the greateſt diſtance from the ſun, approach the neareſt to him at their return.

Their motions in the heavens are not all direct, or according to the order of the ſigns, like thoſe of the other planets. The number of thoſe which move in a retrograde manner, is nearly equal to thoſe whoſe motion is direct.

The orbits of moſt of them are inclined in very large angles to the plane of the ecliptic.

The velocity with which they move is variable in every part of their orbit: when they are near the ſun, they move with incredible ſwiftneſs; when very remote from him, their motion is inconceivably ſlow.

When they appear, they come in a direct line towards the ſun, as if they were going to fall into his body; and after having difappeared for fome time, and in confequence of his extreme brightnefs, they fly off on the other fide as faft as they came, continually lofing their fplendor, till at laft they totally difappear. Their apparent magnitude is very different; fometimes feeming not bigger than the fixed ftars, at other times equal in diameter to Venus. Hevelius obferved one in 1652, which was not inferior to the moon in fize, though not fo bright: it's light pale and dim, it's afpect difmal.

A greater number of comets are feen in the hemifphere towards the fun, than in the oppofite; and are generally invifible at a fmaller diftance than that of Jupiter. Mr. Brydone obferved one at Palermo, in July 1770, which, in twenty-four hours, defcribed an arch in the heavens upwards of fifty degrees in length; fo that, if it was far diftant from the fun, it muft have moved at the rate of upwards of fixty millions of miles in a day.

They differ alfo in form from the other planets, confifting of a large internal body, which fhines with the reflected light of the fun, and is encompaffed with a very large atmofphere, apparently of a fine matter, much refembling that of the aurora borealis: this is called the head of the comet, and the internal part the nucleus. When a comet arrives at a certain diſtance from the ſun, an exhalation ariſes from it, which is called the tail.

The tail is always directed to that part of the heavens which is directly or nearly oppoſite to the ſun, and is greater and brighter after the comet has paſſed it's perihelium, than in it's approach to it; being greateſt of all when it has juſt paſſed the perihelium. The tail of the comet of 1680 was of a prodigious ſize, extending from the head to a diſtance ſcarcely inferior to that of the ſun from the earth.

No ſatiſfactory knowledge has been acquired concerning the cauſe of that train of light which accompanies the comets. Some philoſophers imagine that it is the rarer atmoſphere of the comet, impelled by the ſun's rays. Others, that it is the atmoſphere of the comet riſing in the ſolar atmoſphere, by it's ſpecific levity: while others imagine that it is a phenomenon of the ſame kind with the aurora borealis, and that this earth would appear like a comet to a ſpectator placed in another planet.

The number of the comets is certainly very great, conſiderably beyond any eſtimation that might be made from the obſervations we now poſſeſs.

Though *aſtronomers* have beſtowed much labour in calculating the periods of comets, and much attention to account for their phenomena, yet experience bears no teſtimony in favour of their opinions, nor have modern calculators had better ſucceſs. Indeed the immenſe diſtances to which they are ſuppoſed to run out, are entirely hypothetical.

There are, who do not think the preſent aſtronomy of comets well eſtabliſhed; and as ſo many ſmall ones are frequently ſeen, they think that nothing can be determined with certainty, till ſome better marks are diſcovered for diſtinguiſhing one from another, than any at preſent known; and that even the accompliſhment of Dr. Halley's prediction is uncertain; for it is very ſingular, that out of four years, in which three comets appeared, the only one in which no comet was to be ſeen, ſhould be that very year in which the greateſt aſtronomers that ever exiſted had foretold the appearance of one; and in accounting for it's non-appearance, Mr. Clairault would have been equally ſupported by cometic evidence, whether he had concluded the comet to have been retarded or accelerated by the action of Jupiter and Saturn. A comet appeared in 1757, as well as in 1755; and had he determined the retardation of the comet to be twice as great as he did, another appeared in 1760 to have verified his calculations.

Of the Telescopic Appearance of the Planets.

Though by the teleſcope we have been led onward in our advances towards a more perfect knowledge of the heavenly bodies, and aſtronomy being raiſed from little more than a catalogue of ſtars into a ſcience; yet by this inſtrument men have been led into errors, and aſtronomers have indulged in ſpeculations that equally deviate from ſound reaſon, and the plain dictates of common ſenſe.

The generality of mankind, in all ages, have conſidered the *ſun* as a maſs of pure elementary fire, ſubſiſting from the creation, and ſupported by ſome unknown cauſe, without any occaſion for the groſs fuel neceſſary for ſupporting our terreſtrial fires. The conjectures of aſtronomers have neither been ſo ſimple nor ſo rational; limited in their conceptions, they have not been able to perceive how fire of any kind could ſubſiſt without fuel, and have therefore ſuppoſed the ſun and the earth to be of a ſimilar ſubſtance, and conſequently, that the earth itſelf would be a ſun if ſet on fire. Sir Iſaac Newton has even propoſed it as a query, whether the ſun and fixed ſtars are not *great earths* made vehemently hot, whoſe parts are kept from fuming away by the vaſt weight and denſity of their ſuperincumbent atmoſphere, and whoſe heat is preſerved by the prodigious action and re-action of their parts? Others have imagined the ſun to be a body of quite a different nature, and have even denied him to be poſſeſſed of any inherent heat, though they allow him the power of producing it in other bodies. Some have ſuppoſed, that the main body of the ſun has neither light nor heat, but that it conſiſts of *a vaſt dark globe*, ſurrounded on all ſides with a thin covering of aerial or foggy matter immenſely ſplendid, which gives him the power he poſſeſſes, &c. &c.

The only foundation for theſe wild conjectures, is the appearance of the ſun through teleſcopes. By viewing it through theſe inſtruments, his face is found not to be equally bright in all it's parts. A ſlightly ſpotted appearance, chiefly on or near the edges, is commonly taken notice of; and very frequently dark ſpots of various ſhapes and ſizes are perceived traverſing the diſk from one edge to the other. Theſe ſpots appear at uncertain intervals, and often change their form while they are paſſing over the ſolar diſk, or are broken in pieces, enlarge, and diminiſh by cauſes of which we are ignorant.

Thoſe who adhere to the *conjectures* of Sir I. Newton, ſuppoſe the ſpots to be the ſmoke of new and immenſe volcanoes breaking out in the body of the ſun himſelf; while thoſe who are pleaſed with the *ſuppoſitions* of Profeſſor Wilſon, imagine them to be the dark globe rendered viſible by the diſplacement of the ſhining and ſurrounding matter.

Though it would be deviating from our plan, to ſpend our time in ſpeculations on ſubjects removed ſo far beyond the reach of human inveſtigation; yet we can ſcarce refrain from obſerving, that there is no foundation for ſuppoſing that the ſun has any ſolid body. *Meteors*, reſembling that glorious luminary in ſplendor, have been known to ariſe in the higher parts of our atmoſphere, though their continuance there has been but for a ſhort time. No one ſuppoſes that they have any ſolid body. It is not therefore unreaſonable to ſuppoſe the ſun to be a vaſt collection of elementary fire and light, which being ſent out from him, by means unknown to us, and having accompliſhed the purpoſes for which they are deſigned, perpetually return to him, are ſent out again, and ſo on. Thus the ſun continues to burn unſupported by any terreſtrial fuel, and without the leaſt tendency to diminution, or poſſibility of decay.

Of the Moon. From the appearance of this luminary through a teleſcope, it ſeems probable, that there are great inequalities on her ſurface. Viewing her at any time, except when full, we ſee one of the ſides notched and toothed like a ſaw. Many ſmall points appear like ſtars at a ſmall diſtance from the main luminous body, which join it in a little time. Theſe are conſidered as the tops of high mountains, which catch the light of the ſun ſooner than the other parts which are lower. That theſe very ſhining parts are higher than the reſt of the ſurface, is evident from the appearance of their ſhadows, which lengthen and ſhorten according to their ſituation with reſpect to the ſun. Some aſtronomers have undoubtedly made the mountains of the moon extravagantly high; they have been much reduced by modern calculators. Dr. Herſchel has thought he diſcovered volcanoes on her diſk. And it is ſuppoſed ſhe has an atmoſphere, becauſe the limb of the ſun has been obſerved to tremble juſt before the beginning of a ſolar eclipſe, and becauſe the planets become oval at the beginning of an occultation behind the moon.

Mercury being always near the ſun, nothing more is diſtinguiſhed by the teleſcope, than a variation of his figure, which is ſometimes that of a half moon, ſometimes a little more or leſs than half.

Venus, when in the form of a creſcent, and at her brighteſt times, affords a very pleaſing telescopic view, her surface being diversified with spots like the the moon. The diurnal motion of this planet, both as to it's period and direction, has not hitherto been decidedly ascertained: Dr. Herschel concludes from his observations, that it's atmosphere is very considerable. He has not been able to find the least trace of mountains, and ridicules those observers who have seen such as exceed four, five, and even six times the height of Chimbo Raco, the highest of our mountains.

Mars always appears round except at the quadratures, when it's disk is like that of the moon about three days after the full. It's atmosphere is from the ruddiness of the planet supposed to be very dense; spots are discovered on his surface, but they do not appear fixed: Dr. Herschel has observed two white luminous circles surrounding the poles of this planet, which he supposes to arise from the snow lying about those parts.

The surface of *Jupiter* is distinguished by certain *bands* or *belts*, of a duskier colour than the rest of his surface, running parallel to each other and to the plane of his orbit. They are neither regular nor constant in their appearance, sometimes more, sometimes fewer being perceived; their breadth varies, and sometimes one or more spots are formed between the belts.

Saturn's diſtance does not permit us with common inſtruments to diſtinguiſh many varieties on his ſurface, but his *ring* is a fruitful ſource for aſtronomical ſpeculation. Dr. Herſchel, by means of his powerful inſtruments, has diſcovered a multiplicity of regular belts, which did not change much during the courſe of his obſervations. From theſe he has found, that Saturn has a pretty quick rotation upon it's axis, which he has fixed at 10 h. 16 min. 0 ſec. He has alſo ſhewn, that the ring of Saturn is diviſible into two concentric rings of unequal dimenſions and breadth, ſituated in one plane which is probably not much inclined to the equator of the planet. Theſe rings are at a conſiderable diſtance from each other, the ſmalleſt being much leſs in diameter at the outſide, than the largeſt is at the inſide: the two rings are entirely detached from each other, ſo as plainly to permit the open heavens to be ſeen through the vacancy between them.

Though much has been unfolded to you in the courſe of this eſſay, upon a little conſideration, you will find the things, of which you remain ignorant, infinitely exceed thoſe which you know. It is with us as with a *child*, that thinks if he could but juſt come to ſuch a field, or climb to the top of ſuch a hill, he ſhould be able to touch the ſky; but no ſooner is he come thither, than he finds it as far off as it was before.

It may perhaps be uſeful to point out to you the littleneſs of human knowledge, even in thoſe ſubjects of which we have been treating; and this I ſhall do principally in the words of a late writer.

How far does the univerſe extend, and where are the limits thereof? Where did the CREATOR "ſtay his rapid wheels?" where "fix the golden compaſſes?" Certainly HIMSELF alone is without bounds, but all HIS works are finite. He muſt therefore have ſaid, at ſome point of ſpace,

———"Be theſe thy bounds;
"This be the juſt circumference, O world!"

Here the *mathematician* muſt be ſilent, and wave all calculations, as there can be no ratio between bounded and boundleſs ſpace, even though the magnitude of the former were taken at the utmoſt limit *man* can conceive, or numbers expreſs. But where are the boundaries? Who can tell? All beyond the fixed ſtars is utterly hid from the children of men.

But what do we know of the *fixed ſtars?* A great deal, one would imagine; ſince, like the MOST HIGH, we too *tell* their *numbers*, yea, and *call them by their names!* But what are thoſe that are named, in compariſon with thoſe which our glaſſes diſcover? What are two or three thouſand, to thoſe we diſcover in the milky way alone? How many then are there in the whole expanſe? But to what end do they ſerve? To illuminate worlds, and impart light and heat to their ſeveral choirs of planets? or to gild the extremities of the ſolar ſphere, and miniſter to the perpetual circulation of light and ſpirit?

What are *comets?* Planets not full formed, or planets deſtroyed by conflagration? or bodies of an wholly different nature, of which we can form no idea? How *eaſy* it is to form a thouſand *conjectures!* how *hard* to determine any thing concerning them! Can their huge *revolutions* be even tolerably accounted for on the principles of gravitation and projection? What brings them back, when they have travelled ſo immenſely far? or what whirls them on, when, reaſoning juſtly on the ſame powers, they ſhould drop into the ſolar fire?

What is the *ſun* itſelf? It is undoubtedly the moſt glorious of all the inanimate creatures; and it's uſe we know. GOD made it to *rule the day*. It is

"Of this great world both eye and ſoul."

But who knows of what ſubſtance it is compoſed, or even whether it be ſolid or fluid? What are the ſpots on it's ſurface? what it's real magnitude? Here is an unbounded field for *conjecture;* but what foundation for real knowledge?

What do we know of the feebly-ſhining bodies the *planets*, that move regularly round the ſun? Their revolutions we are acquainted with; but who can regularly demonſtrate to us either their *magnitude* or their diſtance, unleſs he aſſumes it in the uſual way, inferring their magnitude from their diſtance, and the diſtance from the magnitude. What are Jupiter's belts? What is Saturn's ring? The honeſt ploughman knows as well as the moſt learned aſtronomer.

"Sir Iſaac Newton certainly diſcovered more of the dependencies, connections, and relations of the great ſyſtem of the univerſe, than had, previous to his time, been conceded to human penetration: yet was he forced to bottom all his reaſoning on the *hypotheſis of gravitation;* of which he could give no other account, than that it was neceſſary to the concluſions he reſted upon it."

AN

ESSAY,

ON THE USE OF THE

Celestial and Terrestrial

GLOBES;

EXEMPLIFIED IN A GREATER VARIETY OF PROBLEMS, THAN ARE TO BE FOUND IN ANY OTHER WORK;

Exhibiting the general Principles of

DIALING AND NAVIGATION.

BY THE LATE

GEORGE ADAMS,

Mathematical Instrument Maker to His Majesty, and Optician to the Prince of Wales.

FIFTH EDITION.

WITH THE AUTHOR'S LAST IMPROVEMENTS,

Illustrated with Copper Plates.

PHILADELPHIA:

PUBLISHED BY WILLIAM W. WOODWARD,

No. 52, South Second Street.

1808.

Dickinson, Printer.

CONTENTS.

PREFACE

TO THE ESSAY ON THE GLOBES.

THE connection of astronomy with geography is so evident, and both in conjunction so necessary to a liberal education, that no man will be thought to have deserved ill of the republic of letters, who has applied his endeavours to diffuse more universally the knowledge of these useful Sciences, or to render the attainment of them easier; for as no branch of literature can be fully comprehended without them, so there is none which impresses more pleasing ideas on the mind, or that affords it a more rational entertainment.

In the present work, several objections to former editions are obviated; the Problems arranged in a more methodical manner, and a great number added. Such facts are also occasionally introduced, such observations interspersed, and such relative information communicated, as it is presumed will excite curiosity, and fit attention.

To further the design, the attention is directed to the appearance of the planetary bodies, as observed from the earth. It were to be wished that the tutor would at this part exhibit to his pupil the various phenomena in the heavens themselves; by teaching him thus to observe for himself, he would not only raise his curiosity, but so fix the impressions which the objects have made on his mind, that by proper cultivation they would prove a fruitful source of useful employment; and he would therby also gratify that eager desire after novelty, which continually animates young minds, and furnishes them with objects on which to exercise their natural activity.

PART I.

A TREATISE

ON THE USE OF THE TERRESTRIAL AND CELESTIAL GLOBES.

OF THE ADVANTAGES OF GLOBES IN GENERAL, FOR ILLUSTRATING THE PRIMARY PRINCIPLES OF ASTRONOMY AND GEOGRAPHY; AND PARTICULARLY OF THE ADVANTAGES OF THE GLOBES, WHEN MOUNTED IN MY FATHER'S MANNER.

UNIVERSAL approbation, the opinion of those that excel in science, and the experience of those that are learning, all concur to prove that the artificial representations of the earth and heavens, on the terrestrial and celestial globes, are the instruments the best adapted to convey natural and genuine ideas of astronomy and geography to young minds.

This superiority they derive principally from their form and figure, which communicates a more just idea, and gives a more adequate representation of the earth and heavens, than can be formed from any other figure.

To understand the nature of the projection of either sphere in plano, requires more knowledge of geometry than is generally possessed by beginners, it's principles are more recluse, and the solution of problems more obscure.

The motion of the earth upon it's axis is one of the most important principles both in geography and astronomy; on it the greater part of the phenomena of the visible world depend: but there is no invention that can communicate so natural a representation of this motion, as that of a terrestrial globe about it's axis. By a celestial globe, the apparent motion of the heavens is also represented in a natural and satisfactory manner.

In order to convey a clear idea of the various divisions of the earth, of the situation of different places, and to obtain an easy solution of the various problems in geography, it is necessary to conceive many imaginary circles delineated on it's surface, and to understand their relation to each other. Now on a globe these circles have their true form; their intersections and relative positions are visible upon the most cursory inspection. But in projections of the sphere in plano, the form of these circles is varied, and their nature changed; they are consequently but ill adapted to convey to young minds the elementary principles of geography.

On a globe, the appearance of the land and water is perfectly natural and continuous, fitted to convey accurate ideas, and leave permanent impressions on the most tender minds; whereas in planispheres one-half of the globe is separated and disjoined from the other; and those parts, which are contiguous on a globe, are here separated and thrown at a distance from each other. The celestial globe has the same superiority over projections of the heavens in plano.

The globe exhibits every thing in true proportion, both of figure and size; while on a planisphere the reverse may often be observed.

Presuming that these reasons sufficiently evince the great advantage of globes over either planispheres or maps, for obtaining the first principles of astronomical and geographical knowledge, I proceed to point out the pre-eminence of globes *mounted in my father's manner*, over the common, or rather the old and Ptolemaic mode of fitting them up.

The great and increasing sale of his globes mounted in the best manner, may be looked upon at least as a proof of approbation from numbers; to this I might also add, the encouragement they have received from the principal tutors of both our universities, the public sanction of the university of Leyden, the many editions of my father's treatise on their use, and its translation into Dutch, &c. The recommendation of Mess. Arden, Walker, Burton, &c. public lecturers in natural philosophy, might also be adduced: but leaving these considerations, I shall proceed to enumerate the reasons which give them, in my opinion, a decided preference over every other kind of mounting.*

* The following note from Mr. Walker's Easy Introduction to Geography, in favour of my father's globes, will not, I hope, be deemed improper.

" Simplicity and perspicuity should ever be studied by those who cultivate the young mind; and jarring, opposing, or equivocal ideas should be avoided almost as much as error or falsehood. Our globes, till of late years, were equipt with an hour circle, which prevented the poles from sliding through the horizon; hence their rectification was generally for the *place on the earth*, instead of the *sun's place in the ecliptic;* which put the globe into so unnatural and absurd a position respecting the sun, that young people were confounded when they compared it with the earth's positions during it's annual rotation round that luminary, and considering the horizon as the boundary of day and night. Being, therefore, sometimes obliged to rectify for the place on the earth, and sometimes for the sun's place in the ecliptic, the two rules clash so unhappily in the pupil's mind, that few remember a single problem a twelvemonth after the end of their tuition. Globes, therefore, with a horary circle, are but partially described in this treatise; the great intention of which is, to make the elevations and

The earth, by it's diurnal revolution on it's axis, is carried round from west to east. To represent this real motion of the earth, and to solve problems agreeable thereto, it is necessary that the globe, in the solution of every problem, should be moved from *west to east*; and for this purpose, that the divisions on the large brass circle should be on that side which looks westward.* Now this is the case in my father's mode of mounting the globes, and the tutor can thereby explain with ease the rationale of any problem to his pupil. But in the common mode of mounting, the globe must be moved from east to west, according to the Ptolemaic system; and consequently, if the tutor endeavours to shew how things obtain in nature, he must make his pupil unlearn in a degree what he has taught him, and by abstraction reverse the method he has instructed him to use; a practice that we hope will not be adopted by many.

depressions of the poles of a terrestrial globe to represent *all* the situations the earth is in to the sun, for every day or hour through the year. The globes of *Mr. Adams* are the most favourable for the above mode of rectification of any plates we have at present; and to make a quiescent globe to represent all the positions of one revolving round the sun, turning on an inclined axis, and keeping that axis altogether parallel to itself, his globes are better adapted than any, I believe, in being."

* See the Rev. Mr. Hutchin's New Treatise on the Globes.

The celestial globe being intended to represent the apparent motion of the heavens, should be moved, when used, from east to west.

Of the phenomena to be explained by the terrestrial globe, the most material are those which relate to the changes in the seasons; all the problems connected with, or depending upon these phenomena, are explained in a clear, familiar, and natural manner, by the globe, when mounted in my father's mode; for on rectifying it for any particular day of the month, it immediately exhibits to the pupil the exact situation of the globe of the earth for that day; and while he is solving his problem, the reason and foundation of it presents itself to the eye and understanding.

The globe may also be placed with ease in the position of a right sphere; a circumstance exceedingly useful, and which the old construction of the globes did not admit of.

By the application of a moveable meridian, and an artificial horizon connected with it, it is easy to explain why the sun, although he be always in one and the same place, appears to the inhabitants of the earth at different altitudes, and in different azimuths, which cannot be so readily done with the common globes.

On the celestial globe there is a moveable circle of declination, with an artificial sun.

The brass wires placed under the globes, serve to distinguish, in a natural and satisfactory manner, twilight from total darkness, and the reason of the length of it's duration.

The next point, wherein they materially differ from other globes, is in the hour circle. Now it must be confessed, that to every contrivance that has been used for this purpose there is some objection, and probably no mode can be hit upon that will be perfectly free from them. The method adopted by my father appears to me the least exceptionable, and to possess some advantages over every other method I am acquainted with. Agreeably to the opinion of the first astronomers, among others of M. de la Lande, he uses the equator for the hour circle, not only as the largest, but also as the most natural circle that could be employed for that purpose, and by which alone the solution of problems could be obtained with the greatest accuracy. As on the terrestrial globe, the longitude of different places is reckoned on this circle; and on the celestial, the right ascension of the stars, &c. it familiarizes the young pupil with them, and their reduction to time. This method does not in the least impede the motion of the globe; but while it affords an equal facility of elevating either the north or south pole, it prevents the pupil from placing them in a wrong position; while the horary wire secures the globe from falling out of the frame.

Another circumstance peculiar to these globes, is the mode of fixing the compass. It is self-evident, that the tutor, who is willing to give correct ideas to his pupil, should always make him keep the globes with the north pole directed towards the north pole of the heavens, and that, both in the solution of problems, and the explanation of phenomena. By means of the compass, the terrestrial globe is made to supply the purpose of a tellurian, when such an instrument is not at hand. I cannot terminate this paragraph, without testifying my disapprobation of a mode adopted by some, of making the globe turn round upon a pin in the pillar on which it is supported; a mode, that, while it can give little but relief to indolence, is less firm in it's construction, and tends to introduce much confusion in the mind of the pupil.

In order to prevent that confusion and perplexity which necessarily arises in a young mind, when names are made use of which do not properly characterize the subject, my father found it necessary, with Mr. Hutchins, to term that broad wooden circle which supports the globe, and on which the signs of the ecliptic and the days of the month are engraved, the *broad paper circle*, instead of horizon, by which it had been heretofore denominated. The propriety of this change will be evident to all those who consider, that this circle in some cases represents that which divides light from darkness, in others the horizon, and sometimes the ecliptic. For similar reasons, he was induced to call the brazen circle, in which the globes are suspended, the *strong brass circle.*

In a word, many operations may be performed by these globes, which cannot be solved by those mounted in the common manner; while all that they can solve may be performed by these, and that with a greater degree of perspicuity; and many problems may be performed by these at one view, which on the other globes require successive operations.

But as, notwithstanding their superiority, the difference in price may make some persons prefer the old construction, it may be proper to inform them, that they may have my *father's* globes mounted in the *old manner,* at the usual prices.

PART II.

CONTAINING

A DESCRIPTION OF THE GLOBES MOUNTED IN THE BEST MANNER; TOGETHER WITH SOME PRELIMINARY DEFINITIONS.

DEFINITIONS.

BEFORE we begin to discribe the globes, it will be proper to take some notice of the properties of a circle, of which a globe may be said to be constituted.

A *line* is generated by the motion of a point.

Let there be supposed two points, the one moveable, the other fixed.

If the moveable point be made to move directly towards the fixed point, it will generate in it's motion a straight line.

If a moveable point be carried round a fixed point, keeping always the same distance from it, it will generate a *circle*, or some part of a circle, and the fixed point will be the *center* of that circle.

All strait lines going from the center to the circumference of a circle, are equal.

Every strait line that passes through the center of a globe, and is terminated at both ends by it's surface, is called a *diameter*.

The extremities of a diameter are it's poles.

If the circumference of a semicircle be turned round it's diameter, as on an axis, it will generate a globe, or sphere.

The center of the semicircle will be the center of the globe; and as all points of the generating semicircle are at an equal distance from it's center, so all the points of the surface of the generated sphere are at an equal distance from it's center.

DESCRIPTION OF THE GLOBES.

There are two artificial globes. On the surface of one of them the heavens are delineated; this is called the *celestial globe*. The other, on which the surface of the earth is described, is called the *terrestrial globe*.

Fig. 2, plate XIII, represents the celestial, fig. 1, plate XIII, the terrestrial globe, as mounted in my father's manner.

In using the celestial globe, we are to consider ourselves as at the *center.*

In using the terrestrial globe, we are to suppose ourselves on some point of it's *surface.*

The motion of the terrestrial globe represents the *real* motion of the earth.

The motion of the celestial globe represents the *apparent* motion of the heavens.

The motion, therefore, of the celestial globe, is a motion from *east to west.*

But the motion of the terrestrial globe is a motion from *west to east.*

On the surface of each globe several circles are described, to every one of which may be applied what has been said of circles in page 205.

The center of some of these circles is the same with the center of the globe; these are, by way of distinction, called *great circles.*

Of these great circles, some are graduated.

The graduated circles are divided into 360, or equal parts, 90 of which make a quarter of a circle, or a quadrant.

Those circles, whose centers do not pass through the center of the globe, are called *lesser circles.*

The globes are each of them suspended at the poles in a strong brass circle N Z Æ S, and turn therein upon two iron pins, which are the axis of the globe; they have each a thin brass semicircle N H S, moveable about these poles, with a small thin circle H sliding thereon: it is quadrated each way to 90° from the equator to either pole.

On the terrestrial globe this semicircle is a *moveable meridian*. It's small sliding circle, which is divided into a few of the points of the mariner's compass, is called a *terrestrial* or *visible horizon*.

On the celestial globe this semicircle is a *moveable circle of declination*, and it's small brass circle an artificial sun, or planet.

Each globe has a brass wire circle, T W Y, placed at the limits of the crepusculum, or twilight, which, together with the globe, is mounted in a wooden frame. The upper part, B C, is covered with a broad paper circle, whose plane divides the globe into two hemispheres; and the whole is supported by a neat pillar and claw, with a magnetic needle in a compass-box, marked M.

A DESCRIPTION OF THE CIRCLES DESCRIBED ON THE BROAD PAPER CIRCLES B C; TOGETHER WITH A GENERAL ACCOUNT OF IT'S USES.

It contains four concentric circular spaces, the innermost of which is divided into 360°, and numbered into four quadrants, beginning at the east and west points, and proceeding each way to 90°, at the north and south points: these are the four cardinal points of the horizon. The second circular space contains, at equal distances, the thirty-two points of the mariner's compass. Another circular space is divided into twelve equal parts, representing the twelve signs of the zodiac; these are again subdivided into 30 degrees each, between which are engraved their names and characters. This space is connected with a fourth, which contains the calendar of the months and days; each day, on the eighteen-inch globes being divided into four parts, expressing the four cardinal points of the day, according to the Julian reckoning; by which means the sun's place is very nearly obtained for the common years after bissextile, and the intercalary day is inserted without confusion.

In all positions of the celestial globe, this broad paper circle represents the plane of the horizon, and distinguishes the visible from the invisible part of the heavens; *but in the terrestrial globe, it is applied to three different uses.*

1. To distinguish the points of the horizon. In this case it represents the *rational* horizon of any place.

2. It is used to represent the circle of

illumination, or that circle which separates day from night.

3. It occasionally represents the *ecliptic.*

Of the strong brass circle N Æ Z S. One side of this strong brass circle is graduated into four quadrants, each containing 90 degrees.

The numbers on two of these quadrants increase from the equator towards the poles; the other two increase from the poles towards the equator.

Two of the quadrants are numbered from the equator, to shew the distance of any point on the globe from the equator. The other two are numbered from the poles, for the more ready setting the globe to the latitude of any place.

The strong brass circle of the celestial globe is called the meridian, because the centre of the sun comes directly under it at noon.

But as there are other circles on the terrestrial globe, which are called meridians, we chuse to denominate this the *strong brass circle*, or *meridian.*

The graduated side of the strong brass circle, that belongs to the terrestrial globe, should face the *west.*

The graduated side of the strong brazen meridian of the celestial globe, should face the *east.*

On the strong brass circle of the terrestrial globe, and at about 23½ degrees on each side of the north pole, the days of each month are laid down according to the declination of the sun.

Of the Horary Circles, and their Indices. When the globes are mounted in my father's manner, we use the equator as the hour circle; because it is not only the most natural, but also the largest circle that can be applied for that purpose.

To make this circle answer the purpose, a semi-circular wire is placed over it, carrying two indices, one on the east, the other on the west side of the strong brass circle.

As the equator is divided into 360°, or 24 hours, the time of one entire revolution of the earth or heavens, the indices will shew in what space of time any part of such revolution is made among the hours which are graduated below the degrees of the equator on either globe.

As the motion of the terrestrial globe is from west to east, the horary numbers increase according to the direction of that motion: on the celestial globe they increase from the east to the west.

Of the Quadrant of Altitude, Z A. This is a thin, narrow, flexible slip of brass, that will bend to the surface of the globe; it has a nut, with a fiducial line upon it, which may be readily applied to the divisions on the strong brass meridian of either globe. One edge of the quadrant is divided into 90 degrees, and the divisions are continued to 18 degrees below the horizon.

OF SOME OF THE CIRCLES THAT ARE DESCRIBED UPON THE SURFACE OF EACH GLOBE.

We may suppose as many circles to be described on the surface of the earth as we please, and conceive them to be extended to the sphere of the heavens, making thereon concentric circles: for as we are obliged, in order to distinguish one place from another, to appropriate names to them, so are we obliged to use different circles on the globes, to distinguish their parts, and their several relations to each other.

Of the Equator, or Equinoctial. This circle goes round the globe exactly in the middle, between the two poles, from which it always keeps at the same distance; or in other words, it is every where 90 degrees distant from each pole, and is therefore a boundary, separating the northern from the southern hemisphere; hence it is frequently called *the line* by sailors, and when they sail over it they are said to cross the line.

It is that circle in the heavens in which the sun appears to move on those two days, the one in the spring, the other in the autumn, when the days and nights are of an equal length all over the world; and hence on the celestial globe it is generally called the *equinoctial.*

It is graduated into 360 degrees. Upon the terrestrial globe the numbers increase from the meridian of London westward, and proceed quite round to 360. They are also numbered from the same meridian eastward, by an upper row of figures, to accomodate those who use the English tables of latitude and longitude.

On the celestial globe, the equatorial degrees are numbered from the first point of Aries eastward, to 360 degrees.

Under the degrees on either globe is graduated a circle of hours and minutes. On the celestial globe the hours increase eastward, from Aries to XII at Libra, where they begin again in the same direction, and proceed to XII at Aries. But on the terrestrial globe, the horary numbers increase by twice twelve hours westward from the meridian of London to the same again.

In turning the globe about, the equator keeps always under one point of the strong brass meridian, from which point the degrees on the said circle are numbered both ways.

Of the Ecliptic. The graduated circle, which crosses the equator obliquely, forming with it an angle of about 23½ degrees, is called the ecliptic.

This circle is divided into twelve equal parts, each of which contains thirty degrees. The beginning of each of these thirty degrees is marked with the characters of the twelve signs of the zodiac.

The sun appears always in this circle; he advances therein every day nearly a degree, and goes through it exactly in a year.

The points where this circle crosses the equator are called the *equinoctial points.* The one is at the beginning of Aries, the other at the beginning of Libra.

The commencement of Cancer and Capricorn are called the *solstitial points.*

The twelve signs, and their degrees, are laid down on the terrestrial globe; but upon the celestial globe, the days of each month are graduated just under the ecliptic.

The ecliptic belongs principally to the celestial globe.

PART III.

THE USE OF THE TERRESTRIAL GLOBE, MOUNTED IN THE BEST MANNER.

OF LONGITUDE AND LATITUDE, OF TERRESTRIAL MERIDIANS, AND THE PROBLEMS RELATING TO LONGITUDE AND LATITUDE.

MERIDIANS are circular lines, going over the earth's surface, from one pole to the other, and crossing the equator at right angles.

Whatever places these circular lines pass through, in going from pole to pole, they are the meridians of those places.

There are no places upon the surface of the earth, through which meridians may not be conceived to pass. Every place, therefore, is supposed to have a meridian line passing over it's zenith from north to south, and going through the poles of the world.

Thus the meridian of Paris is one meridian; the meridian of London is another. This variety of meridians is satisfactorily represented on the globe, by the moveable meridian, which may be set to every individual point of the equator, and put directly over any particular place.

Whensoever we move towards the east or west, we change our meridian; but we do not change our meridian if we move directly to the north or south.

The moveable meridian shews that the poles of the earth divide every meridian into two semicircles, one of which passes through the place whose meridian it is, the other through a point on the earth, opposite to that place.

Hence it is, that writers in geography and astronomy generally mean by the *meridian* of any place the *semicircle* which passes through that place; these, therefore, may be called the geographical meridians.

All places lying under the same semicircle, are said to have the same meridian; and the semicircle opposite to it is called the opposite meridian, or sometimes the opposite part of the meridian.

From the foregoing definitions, it is clear that the meridian of any place is immoveably fixed to that place, and is carried round along with it by the rotation of the globe.

When the meridian of any place is by the revolution of the earth brought to point at the sun, it is noon, or mid-day, at that place.

The plane of the meridian of any place may be imagined to be extended to the sphere of the fixed stars.

When, by the motion of the earth, the plane of a meridian comes to any point in the heavens, as the sun, moon, &c. that point, &c. is then said to come to the meridian. It is in this sense that we generally use the expression of the sun or stars coming to, or passing over the meridian.

The time which elapses between the noon of any one day in a given place, and the noon of the day following in the same place, is called *a natural day*.

All places which lie under the same meridian, have their noon, and every other hour of the natural day, at the same time. Thus when it is one in the afternoon at London, it is also one in the afternoon to every place under the meridian of London.

In order to ascertain the situation of any point, there must first be a settled part of the earth's surface, from which to measure; and as the point to be ascertained may lie in any part of the earth's surface, and as this surface is spherical, the place from whence we measure must be a circle. It would be necessary, however to establish two such circles; one to know how far any place may be east or west of another, the second to know it's distance north or south of the given point, and thus determine it's precise situation.

Hence it has been customary for geographers to fix upon the meridian of some remarkable place, *as a first meridian, or standard;* and to reckon the distance of any place to the east or west, or it's longitude, by it's distance from the first meridian. On English globes, this first meridian is made to pass through London. The position of this first meridian is arbitrary, because on a globe, properly speaking, there is neither beginning nor end. The first person (whose works at least are come down to us) who computed the distance of places by longitudes and latitudes was Ptolemy, about the year after Christ 140.

The *longitude of any place* is it's distance from the first meridian, measured by degrees on the equator.

To find the longitude of a place, is to find what degree on the equator the meridian of that place crosses.

All places that lie under the same meridian, are said to have the same longitude; all places that lie under different meridians, are said to have different longitudes; this difference may be east or west, and consequently the difference of longitude between any two places, is the distance of their meridians from each other measured on the equator.

Thus if the meridian of any place cuts the equator in a point, which is fifteen degrees east from that point, where the meridian of London cuts the equator, that place is said to differ from London in longitude 15 degrees eastward.

Upon the terrestrial globe there are 24 meridians, dividing the equator into 24 equal parts, which are the hour circles of the places through which they pass.

The distance of these meridians from each other is 15 degrees, or the 24th part of 360 degrees; thus 15 degrees is equal to one hour.

By the rotation of the earth, the plane of every meridian points at the sun, one hour after that meridian which is next to it eastward; and thus they successively point at the sun every hour, so that the planes of the 24 meridian semicircles being extended, pass through the sun in a natural day.

To illustrate this, suppose the plane of the strong brass meridian to coincide with the sun, bring London to this meridian, and then move the globe round, and you will find these 24 meridians successively pass under the strong brass meridian, at one hour's distance from each other; till in 24 hours the earth will return to the same situation, and the meridian of

London will again coincide with the strong brass circle.

By passing the globe round, as in the foregoing article, it will be evident to the pupil, that if one of these meridians, 15 degrees east of London, comes to the strong brass meridian, or points at the sun one hour sooner than the meridian of London, a meridian that is 30 degrees east comes two hours sooner, and so on; and consequently they will have noon, and every other hour, so much sooner than at London: while those, whose meridian is 15 degrees westward from London, will have noon and every other hour of the day, one hour later than at London, and so on, in proportion to the difference of longitude. These definitions being well understood, the pupil will be prepared not only to solve, but see the rationale of the following problems.

PROBLEM I.

To find the Longitude of any place on the Globe.

The reader will find no difficulty in solving this problem, if he recollects the definition we have given of the word longitude, namely, that it is the distance of any place from the first meridian measured on the equator. Therefore, either set the moveable meridian to the place, or bring the place under the strong brass meridian, and that degree of the equator, which is cut by either of the brazen meridians, is the longitude in degrees and minutes, or the hour and minute of its longitude, expressed in time.

As the given place may lie either east or west of the first meridian, the longitude may be expressed accordingly.

It appears most natural to reckon the longitude always westward from the first meridian; but it is customary to reckon one half round the globe eastward, the other half westward from the first meridian. To accomodate those who may prefer either of these plans, there are two sets of numbers on our globes: the numbers nearest the equator increase westward, from the meridian of London quite round the globe to 360°, over which another set of numbers is engraved, which increase the contrary way; so that the longitude may be reckoned upon the equator, either east or west.

Example. Bring Boston, in New England, to the graduated edge of either the strong brass, or of the moveable meridian, and you will find it's longitude in degrees to be $70\frac{1}{2}$, or 4 h. 42 min. in time; Rome $12\frac{1}{2}$ degrees east, or 50 min. in time; Charles-Town, North-America, is 79 deg. 50 min. west.

PROBLEM II.

To find the difference of longitude between any two places.

If the pupil understands what is meant by the difference of longitude, the rule for the solution of this problem will naturally occur to his mind. Now the difference of longitude between any two places is the quantity of an angle (at the pole) made by the meridians of those places measured on the equator. To express this angle upon the globe, bring the moveable meridian to one of the places, and the other place under the strong brass circle, and the required angle is contained between these two meridians, the measure or quantity of which is to be counted on the equator.

Example. I find the longitude of Rome to be 12½ east, that of Constantinople to be 29; the difference is 17½ degrees. Again, I find Jerusalem has 35 deg. 25 min. east longitude from London; and Pekin, in China, 116 deg. 52 min. east longitude; the difference is 81 deg. 27 min.; that is, Pekin is 81 deg. 27 min. east longitude from Jerusalem; or Jerusalem is 81 deg. 27 min. west longitude from Pekin.

If one place is east, and the other west of the first meridian, either find the longitude of both places westward, by that set of numbers which increase westward from the meridian of London to 360 deg. and the difference between the number thus found is the answer to the question :—or, add the east and west longitudes, and the sum is the difference of longitude; thus the longitude of Rome is 12 deg. 30 min. east, of Charles-Town 79 deg. 50 min, west; their sum, 91 deg. 20 min. is the difference required.

It may be proper to observe here, that *the difference of time is the same with the difference of longitude*, consequently that some of the following problems are only particular cases of this problem, or readier modes of computing this difference.

PROBLEM III.

To find all those places where it is noon, at any given hour of the day, at any given place.

General rule. Bring the given place to the brass meridian; and set the index to the uppermost XII; then turn the globe, till the index points to the given hour, and it will be noon to all the places under the meridian.

As the diurnal motion of the earth is from *west to east*, it is plain that all places which are to the east of any meridian, must necessarily pass by the sun before a meridian which is to the west can arrive at it.

N. B. As in my *father's* globes, the XII, or first meridian, passes through London, you have only to bring the given hour to the east of London, if in the morning, to the brass meridian, and all those places which are under it will have noon at the given hour; but bring the given hour westward of London, if it be in the afternoon.

When it is 4 h. 50 min. in the afternoon at Paris, it is noon at New Britain, New England, St. Domingo, Terra Firma, Peru, Chili, and Terra del Fuego.

When it is 7 h. 50 min. in the morning at Ispahan, it is noon at the middle of Siberia, Chinese Tartary, China, Borneo.

PROBLEM IV.

When it is noon at any place, to find what hour of the day it is at any other place.

Rule. Bring the place at which it is noon, to the strong brass meridian, and set the hour index to the uppermost XII, and then turn the globe about till the other place comes under the strong brass meridian, and the hour index will shew upon the equator the required hour. If to the eastward of the place where it is noon, the hour found will be in the afternoon; if to the westward, it will be in the forenoon.

Thus when it is noon at London, it is 50 min. past XII, at Rome; 32 min. past VII in the evening at Canton, in China; 15 min. past VII in the morning at Quebec, in Canada.

PROBLEM V.

The hour being given at any place, to tell what hour it is in any other part of the world.

Rule. Bring the place where the time is required under the strong brass meridian, set the hour index to the given time, then turn the globe, till the other place is under the brass meridian, and the horary index will point to the hour required.

Thus suppose we are at London at IX o'clock in the morning, what is the time at Canton, in China? Answer, 31 min. past IV in the afternoon. When it is IX in the evening at London, it is about 15 min. past IV in the afternoon at Quebec in Canada.

Thus also when it is III in the afternoon at London, it is 18 min. past X in the forenoon at Boston. When it is VI in the morning at the Cape of Good Hope, it is 7 min. after midnight at Quebec.

OF LATITUDE.

I have already observed, that the equator divides the globe into two hemispheres, the northern and the southern.

The latitude of a place is it's distance from the equator towards the north or south pole, measured by degrees upon the meridian of the place.

All places, therefore, that lie under the equator, are said to have *no latitude.*

All other places upon the earth are said to be in north or south latitude, as they are situated on the north or south side of the equator; and the latitude of any place will be greater or less, according as it is farther from, or nearer to the equator.

Lines, which keep always at the same distance from each other, are called *parallels.*

If a circle, or circular line, be conceived keeping at the same distance from the equator, it will be a parallel to the equator.

Circles of this kind are commonly drawn on the terrestrial globe, on both sides of the equator.

A circle of this kind, at 10 degrees from the equator, is called a parallel of 10 degrees.

When any such parallel passes through two places on the globe's surface, those two places have the same latitude.

Hence parallels to the equator are called *parallels of latitude.*

There are four principal lesser circles parallel to the equator, which divide the globe into five unequal parts, called *zones.*

The circle on the north side of the equator is called the *tropic of Cancer;* it just touches the north part of the ecliptic, and shews the path the sun appears to describe, the longest day in summer.

That which is on the south side of the equator is called the *tropic of Capricorn;* it just touches the south part of the ecliptic, and shews the path the sun appears to describe, the shortest day in winter.

The space between these two tropics, which contains about 47 degrees, was called by the ancients the *torrid zone.*

The two polar circles are placed at the same distance from the poles, that the two tropics are from the equator.

One of these is called the *northern,* the other the *southern polar circle.*

These include $23\frac{1}{2}$ degrees on each side of their respective poles, and consequently contain 47 degrees, equal to the number of degrees included between the tropics.

The space contained within the northern

polar circle, was by the ancients called the *north frigid zone;* and that within the southern polar circle, the *south frigid zone.*

The spaces between either polar circle, and its nearest tropic, which contain about 43 degrees each, were called by the ancients the *two temperate zones.*

PROBLEM VI.

To find the latitude of any place.

If the pupil comprehends the foregoing definition, he will find no difficulty in the solution of this and some of the following problems.

Rule. Bring the place to the graduated side of the strong brass meridian, and the degree which is over it is the latitude. Thus London will be found to have 51 deg. 30 min. north latitude; Constantinople 41 deg. north latitude; and the Cape of Good Hope 34 deg. south latitude.

PROBLEM VII.

To find all those places which have the same latitude with any given place.

Suppose the given place to be London; turn the globe round, and all those places which pass under the same point of the strong brass meridian, are in the same latitude.

PROBLEM VIII.

To find the difference of latitude between two places.

Rule. If the places be in the same hemisphere, bring each of them to the meridian, and subtract the latitude of one from the other. If they are in different hemispheres, add the latitude of one to that of the other.

Example. The latitude of London is 51 deg. 32 min.; that of Constantinople 41 deg.; their difference is 10 deg. 32 min. The difference between London, 51 deg. 32 min. north, and the Cape of Good Hope, 34 deg. south, is 84 deg. 32 min.

PROBLEM IX.

The latitude and longitude of any place being known, to find that place upon the globe.

Rule. Seek for the given longitude in the equator, and bring the moveable meridian to that point; then count from the equator on the meridian, the degree of latitude either towards the north or south pole, and bring the artificial horizon to that degree, and the intersection of it's edge with the meridian is the situation required.

By this problem any place not represented on the globe may be laid down thereon, and it may be seen where a ship is when it's latitude and longitude are known.

Example. The latitude of Smyrna, in Asia, is 38 deg. 28 min. north; it's longitude 27 deg. 30 min. east of London; therefore, bring 27 deg. 30 min. counted eastward on the equator, to the moveable meridian, and slide the diameter of the artificial horizon to 38 deg. 28 min. north latitude, and it's center will be correctly placed over Smyrna.

It may be proper in this place just to shew the pupil, that *the latitude of any place is always equal to the elevation of the pole of the same place above the horizon.* The reason of this is, that from the equator to the pole are 90 degrees, from the zenith to the horizon are also 90 degrees; the distance of the zenith to the pole is common to both, and therefore if taken away from both, must leave equal remains; that is, the distance from the equator to the zenith, which is the latitude, is equal to the elevation of the pole.

OF FINDING THE LONGITUDE.

As the finding the longitude of places forms one of the most important problems in geography and astronomy, some further account of it, it is presumed, will prove entertaining and useful to the reader.

"For what can be more interesting to a person in a long voyage, than to be able to tell upon what part of the globe he is, to know how far he has travelled, what distance he has to go, and how he must direct his course to arrive at the place he designs to visit? These important particulars are all determined by knowing the latitude and longitude of the place under consideration. When the discovery of the compass invited the voyager to quit his native shore, and venture himself upon an unknown ocean, that knowledge, which before he deemed of no importance, now became a matter of absolute necessity. Floating in a frail vessel, upon an uncertain abyss, he has consigned himself to the mercy of the winds and waves, and knows not where he is."*

The following instance will prove of what use it is to know the longitude of places at sea. The editor of Lord Anson's voyage, speaking of the island of Julian Fernandez, adds, "The uncertainty we were in of it's position, and our standing in for the main on the 28th of May, in order to secure a sufficient easting, when we were indeed extremely near it, cost us the lives of between 70 and 80 of our men, by our longer continuance at sea; from which fatal accident we might have been exempted, had

* Bonnycastle's Astronomy.

we been furnished with such an account of it's situation, as we could fully have depended on."

The latitude of a place the sailor can easily discover; but the longitude is a subject of the utmost difficulty, for the discovery of which many methods have been devised. It is indeed of so great consequence, that the Parliament of Great Britain proposed a reward of 10,000 *l.* if it extended only to 1 degree of a great circle, or 60 geographical miles; 15,000 *l.* if found to 40 such miles; and 20,000 *l.* to the person that can find it within 30 minutes of a great circle, or 30 geographical miles.

As I cannot enter fully into this subject in these essays, it will, I hope, be deemed sufficient, if I give such an account as will enable the reader to form a general idea of the solution of this important problem.

From what has been seen in the preceding pages, it is evident that 15 degrees in longitude answer to one hour in time, and consequently that the longitude of any place would be known, if we knew their difference in time; or in other words, how much sooner the sun, &c. arrives at the meridian of one place, than that of another, The hours and degrees being in this respect commensurate, it is as proper to express the distance of any place in time as in degrees.

Now it is clear, that this difference in time would be easily ascertained by the observation of any instantaneous appearance in the heavens, at two distant places; for the difference in time at which the same phenomenon is observed, will be the distance of the two places from each other in longitude. On this principle, most of the methods in general use are founded.

Thus if a clock, or watch, was so contrived, as to go uniformly in all seasons, and in all places; such a watch being regulated to London time, would always shew the time of the day at London; then the time of the day under any other meridian being found, the difference between that time, and the corresponding London time, would give the difference in longitude.

For supposing any person possessed of one of these time-pieces, to set out on a journey from London, if his time piece be accurately adjusted, wherever he is, he will always know the hour at London exactly; and when he has proceeded so far either eastward or westward, that a difference is perceived betwixt the hour shewn by his time-piece, and those of the clocks and watches at the places to which he goes, the distance of those places from London in longitude will be known. But to whatever degree of perfection such movements may be made, yet as every mechanical instrument is liable to be injured by various accidents, other methods are obliged to be used, as the eclipses of the sun and moon, or of Jupiter's satellites. Thus supposing the moment of the beginning of an eclipse was at ten o'clock at night at London, and by accounts from two observers in two other places, it appears that it began with one of them at nine o'clock, and with the other at midnight; it is plain, that the place where it began at nine is one hour, or 15 degrees east in longitude from London; the other place where it began at midnight, is 30 degrees distant in west longitude from London. Eclipses of the sun and moon do not, however, happen often enough to answer the purposes of navigation; and the motion of a ship at sea prevents the observations of those of Jupiter's satellites.

If the place of any celestial body be computed, for example, as in an almanack, for every day or to parts of days, to any given meridian, and the place of this celestial body can be found by observation at sea, the difference of time between the time of observation and the computed time, will be the difference of longitude in time. The moon is found to be the most proper celestial object, and the observations of her appulses to any fixed star is reckoned one of the best methods for resolving this difficult problem.

LENGTH OF THE DEGREES OF LONGITUDE.

Supposing the earth to be a perfect globe, the length of a degree upon the meridian has been estimated to be 69,1 miles; but as the earth is an oblate spheroid, the length of a degree on the equator will be somewhat greater.

Whether the earth be considered as a spheroid or a globe, all the meridians intersect one another at the poles. Therefore, the number of miles in a degree must always decrease as you go north or south from the equator. This is evident by inspection of a globe, where the parallels of latitude are found to be smaller in proportion as they are nearer the pole. Hence it is that a degree of longitude is no where the same, but upon the same parallel; and that a degree of longitude is equal to a degree of latitude only upon the equator.

The following *table* shews how many geographical miles, and decimal parts of a mile, would be contained in a degree of longitude, at each degree of latitude from the equator to the poles, if the earth was a perfect sphere, and the circumference of it's equinoctial line 360 degrees, and each degree 60 geographical miles.

This table enables us to determine the velocity with which places upon the globe revolve eastward; for the velocity is different, according to the distance of the places from the equator, being swiftest as passing through a greater space, and so by degrees slower towards the pole, as passing through a less space in the same time. Now as every part of the earth is moved through the space of it's circumference, or 360 degrees, in 24 hours; the space described in one hour is found by deviding 360 by 24, which gives in the quotient 15 degrees; and so many degrees does every place on the earth move in an hour. The number of miles contained in so many degrees in any latitude, is readily found from the table.

Thus under the equator places revolve at the rate of more than 1000 miles in an hour; at London, at the rate of about 640 miles in an hour.

TABLE.

LAT.		LAT.		LAT.	
Deg.	*Miles.*	*Deg.*	*Miles.*	*Deg.*	*Miles.*
00	60,00	10	59,08	20	56,38
1	59,99	11	58,89	21	56,01
2	59,96	12	58,68	22	55,63
3	59,92	13	58,46	23	55,23
4	59,86	14	58,22	24	54,81
5	59,77	15	57,95	25	54,38
6	59,67	16	57,67	26	53,93
7	59,56	17	57,37	27	53,46
8	59,42	18	57,06	28	52,97
9	59,26	19	56,73	29	52,47

LAT.		LAT.		LAT.	
Deg.	*Miles.*	*Deg.*	*Miles.*	*Deg.*	*Miles.*
30	51,96	51	37,76	72	18,55
31	51,43	52	36,94	73	17,54
32	50,88	53	36,11	74	16,53
33	50,32	54	35,26	75	15,52
34	49,74	55	34,41	76	14,51
35	49,15	56	33,55	77	13,50
36	48,54	57	32,68	78	12,47
37	47,92	58	31,79	79	11,45
38	47,28	59	30,90	80	10,42
39	46,62	60	30,00	81	9,38
40	45,95	61	29,09	82	8,35
41	45,28	62	28,17	83	7,32
42	44,59	63	27,24	84	6,28
43	43,88	64	26.30	85	5,23
44	43,16	65	25,36	86	4,18
45	42,43	66	24,41	87	3,14
46	41,68	67	23,45	88	2,09
47	40,92	68	22,48	89	1,05
48	40,15	69	21,50	90	0,00
49	39,36	70	20,52		
50	38,57	71	19,54		

Another circumstance which arises from this difference of meridians in time, must detain us a little before we quit this subject. For from this difference it follows, that if a ship sails round the world, always directing her course eastward, she will at her return home find she has gained one whole day of those that stayed at home; that is, if they reckon it May 1, the ship's company will reckon it May 2; if westward, a day less, or April 30.

This circumstance has been taken notice of by navigators. "It was during our stay at Mindanao, (says Capt. Dampier) that we were first made sensible of the change of time in the course of our voyage: for having travelled so far westward, keeping the same course with the sun, we consequently have gained something insensibly in the length of the particular days, but have lost in the tale the bulk or number of the days or hours.

"According to the different longitudes of England and Mindanao, this isle being about 210 degrees west from the Lizard, the difference of time at our arrival at Mindanao ought to have been about fourteen hours; and so much we should have anticipated our reckoning, have gained it by bearing the sun company.

"Now the natural day in every place must be consonant to itself; but going about with, or against the sun's course, will of necessity make a difference in the calculation of the civil day, between any two places. Accordingly, at Mindanao, and other places in the East Indies, we found both natives and Europeans reckoning a day before us. For the Europeans coming eastward, by the Cape of Good Hope, in a course contrary to the sun and us, wherever we met, were a full day before us in their accounts.

"So among the Indian Mahometans, their Friday was Thursday with us; though it was Friday also with those that came eastward from Europe.

"Yet at the Ladrone islands we found the Spaniards of Guam keeping the same computation with ourselves; the reason of which I take to be, that they settled that colony by a course westward from Spain; the Spaniards going first to America and thence to the Ladrone islands."

It is clear, from what has been said in the first part of this article, concerning both latitude and longitude, that if a person travel ever so far directly towards east or west, his latitude would be always the same, though his longitude would be continually changing.

But if he went directly north or south, his longitude would continue the same, but his latitude would be perpetually varying.

If he went obliquely, he would change both his latitude and longitude.

The longitude and latitude of places give only their relative distances on the globe; to discover, therefore, their real distance, we have recourse to the following problem.

PROBLEM X.

Any place being given, to find the distance of that place from another, in a great circle of the earth.

I shall divide this problem into three cases.

Case 1. If the places lie under the same meridian. Bring them up to the meridian, and mark the number of degrees intercepted between them. Multiply the number of degrees thus found by 60, and they will give the number of geographical miles between the two places. But if we would have the number of English miles, the degrees before found must be multiplied by 69½.

Case 2. If the places lie under the equator. Find their difference of longitude in degrees, and multiply, as in the preceding case, by 60 or 69½.

Case 3. If the places lie neither under the same meridian, nor under the equator. Then lay the quadrant of altitude over the two places, and mark the number of degrees intercepted between them. These degrees multiplied as above mentioned, will give the required distance.

PROBLEM XI.

To find the angle of position of places.

The angle of position is that formed between the meridian of one of the places, and a great circle passing through the other place.

Rectify the globe to the latitude and zenith of one of the places, bring that place to the strong brass meridian, set the graduated edge of the quadrant to the other place, and the number of degrees contained between it and the strong brass meridian, is the measure of the angle sought. Thus,

The angle of position between the meridian of Cape Clear, in Ireland, and St. Augustine, in Florida, is about 82 degrees south westerly; but the angle of position between St. Augustine and Cape Clear, is only about 46 degrees north easterly.

Hence it is plain, that the line of position, or azimuth, is not the same from either place to the other, as the romb-line are.

PROBLEM XII.

To find the bearing of one place from another.

The bearing of one sea-port from another is determined by a kind of spiral, called a romb-line, passing from one to the other, so as to make equal angles with all the meridians it passes by; therefore, if both places are situated on the same parallel of latitude, their bearing is either east or west from each other; if they are upon the same meridian, they bear north and south from one another; if they lie upon a romb-line, their bearing is the same with it; if they do not, observe to which romb-line the two places are nearest parallel, and that will shew the bearing sought.

Example. Thus the bearing of the Lizard point from the island of Bermudas is nearly E. N. E.; and that of Bermudas from the Lizard is W. S. W. both nearly upon the same romb-line, but in contrary directions.

OF THE TWILIGHT.

That light which we have from the sun before it rises, and after it sets, is called the *twilight*.

The morning twilight, or day break, commences when the sun comes within eighteen degrees of the horizon, and continues till sun-rising. The evening twilight begins at sun-setting, and continues till it is eighteen degrees below the horizon.

To illustrate the causes of the various length of twilight in different places, a wire circle is fixed eighteen degrees below the surface of the broad paper circle; so that all those places which are above the wire circle will have twilight, but it will be dark to all those places below it.

I have already observed, that it is owing to the atmosphere that we are favoured with the light of the sun before he is above, and after he is below, our horizon. Hence, though after sun-setting we receive no direct light from the sun, yet we enjoy his reflected light for some time; so that the darkness of the night does not come on suddenly, but by degrees.

In a right position of the sphere the twilights are quickly over, because the sun rises and sets nearly in a perpendicular; but in an oblique sphere they last longer, the sun rising and setting obliquely. The greater the latitude of the place, the longer is the duration of the twilight; so that all those who are in 49 degrees of latitude have in the summer, near the solstice, their atmosphere enlightened the whole night, the twilight lasting till sun-rising.

In a parallel sphere, the twilight lasts for several months; so that the inhabitants of this position have either direct or reflex light of the sun nearly all the year, as will plainly appear by the globe.

OF THE DIURNAL MOTION OF THE EARTH, AND THE PROBLEMS DEPENDING ON THAT MOTION.

As the daily motion of the earth about it's axis, and the phenomena dependent on it, are some of the most essential points which a beginner ought to have in view, we shall now endeavour to explain them by the globes; and here I think the advantage of globes mounted in my father's manner, over those generally used, will be very evident.

I have already observed, that in globes mounted in our manner, the motion of the terrestrial globe about it's axis represents the diurnal motion of the earth, and that the horary index will point out upon the equator the 24 hours of one diurnal rotation, or any part of that time.

I shall now consider *the broad paper circle as the plane which distinguishes light from darkness*; that is, the enlightened half of the earth's surface, from that which is not enlightened.

For when the sun shines upon a globe, he shines only upon one half of it; that is, one half of the globe's surface is enlightened by him, the other not.

That the enlightened half may be that half which is above the broad paper circle, we must imagine the sun to be in our *zenith*.

Or let a sun be painted on the ceiling over the terrestrial globe, the diameter of the picture equal to the diameter of the globe.

Then all those places that are above the broad paper circle will be in the sun's light; that is, it will be *day* in all those places.

And all places that are below this circle, will be out of the sun's light; that is, in all those places it will be *night*.

When any place on the earth's surface comes to the edge of the broad paper circle, passing out of the shade into the light, the sun will appear *rising* at that place.

And when a place is at the edge of the broad paper circle, going out of the light into the shade, the sun will appear at that place to be *setting*.

When we view the globe in this position, we at once see the situation of all places in the illuminated hemisphere, whose inhabitants enjoy the light of the day. One edge of the broad paper circle shews at what place the sun appears rising at the *same* time; and the opposite edge shews at what places the sun is setting at the same time.

The horary index shews how long a place is moving from one edge to the other; that is, how long the day or night is at that place;

and, consequently, when the globe is thus situated, you readily discover the time of the sun's rising and setting on any given day, in any given place.

TO RECTIFY THE TERRESTRIAL GLOBE.

To rectify the terrestrial globe, is to place it in the same position in which our earth stands to the sun, at all or at any given times.

That half of the earth's surface which is enlightened by the sun is not always the same; it differs according as the sun's declination differs.

To rectify, then, the terrestrial globe, is to bring it into such a position, as that the enlightened half of the earth's surface may be all above the broad paper circle.

On the back side of the strong brass meridian, and on each side of the north pole, the months and days of the month are graduated in two concentric spaces, agreeable to the declination of the sun.

Bring the day of the month that is graduated on the back side of the strong brass meridian, to coincide with the broad paper circle, and the globe is rectified.

Thus set the first of May to coincide with the broad paper circle, and that half of the earth's surface which is enlightened at any time upon that day, will be all at once above the said circle.

If the horary index be set to XII, when any particular place is brought under the strong brass meridian, it will shew the precise time of sun-rising and sun-setting at that place, according as that place is brought to the eastern or western edge of the broad paper circle.

It will also shew how long any place is in moving from the east to the west side of the illuminated disk, and thence the length of the day and night.

It will also point out the length of the twilight, by shewing the time in which the place is passing from the twilight circle to the edge of the broad paper circle on the western side; or from the edge of this circle on the eastern side, to the twilight wire, and thus determine the length of the whole artificial day.

N. B. The twilight wire is placed at 18 degrees from the broad paper circle.

I shall now proceed to exemplify upon the globes these particulars, at three different seasons of the year, viz. the summer solstice, the winter solstice, and the time or times of the equinoxes.

PROBLEM XIII.

To place the globe in the same situation, with respect to the sun, as our earth is in at the time of the SUMMER SOLSTICE.

Rectify the globe to the extremity of the divisions for the month of June, or 23½ degrees north declination; that is, bring these divisions on the strong brass meridian to coincide with the plane of the broad paper circle.

Then that part of the earth's surface, which is within the northern polar circle, will be above the broad paper circle, and will be in the light, and the inhabitants thereof will have no night.

But all that space which is contained within the southern polar circle, will continue in the shade; that is, it will there be continual night.

In this position of the globe, the pupil will observe how much the diurnal arches of the parallels of latitude decrease, as they are more and more distant from the elevated pole.

If any place be brought under the strong brass meridian, and the horary index is set to that XII which is most elevated, and the place be afterwards brought to the western side of the broad paper circle, the hour index will shew the time of sun-rising; and when the place is moved to the eastern edge, the index points to the time of sun-setting.

The length of the day is obtained by the time shewn by the horary index, while the globe moves from the west to the east side of the broad paper circle.

Thus it will be found, that at London the sun rises about 15 minutes before IV in the morning, and sets about 15 minutes after VIII at night.

At the following places it will be nearly at the times expressed in the table.

	☉ Rising.		☉ Setting.		Length of day.		Twi-light.	
	h.	*m.*	*h.*	*m.*	*h.*	*m.*	*h.*	*m.*
Cape Horn - -	8	44	3	16	6	32	2	35
Cape of Good Hope	7	9	4	51	9	42	1	43
Rio de Janeiro, in Brazil	6	42	5	19	10	38	1	23
Island of St. Thomas's near the equator.	6		6		12		1	20
Cape Lucas, California	5	12	6	48	13	36	1	35

We also see, that at the same time the sun is rising at London, it is rising at the isles of Sicily and Madagascar.

And, that at the same time when the sun sets at London it is setting at the island of Madeira, and at Cape Horn.

And when the sun is setting at the island of Borneo, in the East Indies, it is rising at Florida, in America. And many other similar circumstances relative to other places, are seen as it were by inspection.

PROBLEM XIV.

To explain the situation of the earth, with respect to the sun, at the time of the WINTER SOLSTICE.

Rectify the globe to the extremity of the divisions for the month of December, or to 23½ degrees south declination.

When it will be apparent that the whole space within the southern polar circle is in the sun's light, and enjoys continual day; whilst that of the northern polar circle is in the shade, and has continual night.

If the globe be turned round, as before, the horary index will shew, that at the several places before-mentioned their days will be respectively equal to what their nights were at the time of the summer solstice.

It will appear farther, that it is now sun-setting at the same time in those places in which it was sun-rising at the same time at the summer solstice; and, on the contrary, sun-rising at the time it then appeared to set.

PROBLEM. XV.

To place the globe in the situation of the earth, at the times of the EQUINOX.

The sun has no declination at the times of the equinox, consequently there must be no elevation of the pole.

Bring the day of the month when the sun enters the first point of Aries, or day of the month when the sun enters the first point of Libra, to the plane of the broad paper circle; then the two poles of the globe will be in that plane also, and the globe will be in the position which is called a *right sphere.*

For it is a right sphere when the two poles are in the plane of the broad paper circle, because then all those circles which are parallel to the equator will be at right angles to that plane.

If the globe be now turned from west to east, it will plainly appear, that all places upon it's surface are twelve hours above the broad paper circle, and twelve hours below it; that is, the days are twelve hours long all over the earth, and the nights are equal to the days, whence these times are called the times of equinox.

Two of these occur in every year; the first is the autumnal, the second the vernal equinox.

At these seasons the sun appears to rise at the same time to all places that are on the same meridian. The sun sets also at the same time in all those places.

Thus if London and Mundford, on the gold coast, be brought to the strong brass meridian, the graduated side of which is in this case the horary index, and they be afterwards carried to the western edge of the broad paper circle, the index will shew that the sun rises at VI at both places; when they are carried to the eastern edge, the index points to VI for the time of sunsetting.

N. B. If London be not the given place, the hour index is to be set to the most elevated XII, while the place is under the graduated edge of the strong brass meridian.

The following circumstances, which usually attend the four cardinal divisions of the year, cannot be better introduced than at this place. At the time of the equinoxes, when the sun passes from one hemisphere into the other, there is almost constantly some disturbance in the weather; the winds are then generally higher: at the vernal equinox they are for the most part easterly, cold, dry, and searching. The solstitial point of the summer is often distinguished by violent rains, and that we call a midsummer flood. The winter being less rainy than the summer, nothing particular happens at the winter solstice, but that the frosts commonly set in more severely, with some quantity of snow upon the ground.

OF THE ARTIFICIAL OR TERRESTRIAL HORIZON.

The brass circle, which may be slipped from pole to pole on the moveable meridian, has been already described. The circumference of it is divided into eight parts, to which are affixed the initial letters of the mariner's compass.

When the center of it is set to any particular place, the situation of any other place is seen, with respect to that place; that is, whether they be east, west, north, or south of it.

It will therefore represent the horizon of that place.

We shall here use this artificial horizon, to shew why the sun, although he be always in one and the same place, appears to the inhabitants of the earth at different altitudes, and in different azimuths.

PROBLEM XVI.

To exemplify the sun's altitude, as observed with an artificial horizon.

The altitude of the sun is greater or less, according as the line which goes from us to the sun is nearer to, or farther off from our horizon.

Let the moveable circle be applied to any place, as London, then will the horizon of London be thereby represented.

The sun is supposed, as before, to be in the zenith, that is, directly over the terrestrial globe.

If then from London a line go vertically upwards, the sun will be seen at London in that line.

At sun-rising, when London is brought to the west edge of the broad paper circle, the supposed line will be parallel to the artificial horizon, and the sun will then be seen in the horizon.

As the globe is gradually turned from the west towards the east, the horizon will recede from that line which goes from London vertically upwards; so that the line in which the sun is seen gets further and further from the horizon; that is, the sun's altitude increases gradually.

When the horizon, and the line which goes from London vertically upwards, are arrived at the strong brass meridian, the sun is then at his greatest or meridian altitude for that day, and the line and horizon are at the largest angle they can make with each other.

After this, the motion of the globe being continued, the angle between the artificial horizon, and the line which goes from London vertically upwards, continually decreases, until London arrives at the eastern edge of the broad paper circle; it's horizon then becomes vertical again, and parallel to the line which goes vertically upwards. The sun will again appear in the horizon, and will set.

PROBLEM XVII.

Of the sun's meridian altitude, at the three different seasons.

Rectify the globe to the time of the winter solstice, by problem xiv, and place the center of the visible horizon on London.

When London is at the graduated edge of the strong brass meridian, the line which goes vertically upwards makes an angle of about 15 degrees; this is the sun's meridian altitude at that season, to the inhabitants of London.

If the globe be rectified to the times of equinox, by problem xv, the horizon will be farther separated from the line which goes vertically upwards, and makes a greater angle therewith, it being about 38½ degrees; this is the sun's meridian altitude, at the time of equinox at London.

Again, rectify to the summer solstice by problem xiii, and you will find the artificial horizon recede farther from the line which goes from London vertically upwards, and the angle it then makes is about 62 degrees, which shews the sun's meridian altitude at the time of the summer solstice.

Hence flows also the following arithmetical problem.

PROBLEM XVIII.

To find the sun's meridian altitude universally.

Add the sun's declination to the elevation of the equator, if the latitude of the place, and the declination of the sun, are both on the same side.

If on contrary sides, subtract the declination from the elevation of the equator, and you obtain the sun's meridian altitude.

Thus the elevation of the equator at London is - - -	38°	28
The sun's declination on the 20th of May - - - -	20	8
Their sum, the sun's meridian altitude that day - - - -	58	36

Again, to the elevation of the equator at London - - -	38°	28
Add the sun's greatest declination at the time of the summer solstice	23	29
The sum is the sun's greatest meridian altitude at London - -	61	57

PROBLEM XIX.

Of the sun's azimuths, as compared with the artificial horizon.

The artificial horizon serves also to determine the sun's azimuths.

An *azimuth* of the sun is denominated from that point of the horizon, to which the sun, or a line going to the sun, is nearest.

Thus if the sun, or a line going to the sun, be nearest the south-east point of the horizon, which point is 45 degrees distant from the meridian, the sun's azimuth is an azimuth of 45 degrees, and the sun will appear in the south-east.

Imagine the sun, as we have done before, to be placed directly over the globe.

In which case, a line going to the sun from any place on the surface of the globe, will have a vertical direction, and will go from that place vertically upwards.

If then we apply the artificial horizon to any place, the point of this horizon to which a vertical line is nearest, shews the sun's azimuth at that time.

It is observable, that the point of the horizon to which such a vertical line is nearest, will be at all times that point which is most elevated.

To exemplify this, let the globe be in the position of a right sphere, and let the artificial horizon be applied to London.

When London is at the western edge of the broad paper circle, which situation represents the time when the sun appears to rise, the eastern point of the artificial horizon being then most elevated, shews that the sun at his rising is due east.

Turn the globe, till London comes to the eastern edge of the broad paper circle, then the western point of the artificial horizon will be most elevated, shewing that the sun sets due west.

Now place the globe in the position of an oblique sphere; and if London be brought to the eastern or western side of the broad paper circle, the vertical line will depart more or less from the east and west points, in which case the sun is said to have more or less *amplitude*.

If the departure be northward, it is called northern amplitude; if southward, it is called southern amplitude.

In whatever position the globe be placed,* when London comes to the strong brass meridian, the most elevated part of the artificial horizon will be the south point of it.

Which shews that at noon the sun will always, and in all seasons, appear in the south.

OF THE ANCIENT DIVISIONS OF THE EARTH INTO ZONES AND CLIMATES.

Climates was a term used by the ancient astronomers to express a division of the earth, which, before the marking down the latitudes of countries into degrees and minutes was in use, served them for dividing the earth into certain portions in the same direction, so as to speak of any particular place with some degree of certainty, though not with due precision.

It was natural for the earliest observers to remark, for one of the first things, the diversity that there was in the sun's rising and setting: it was by this they regulated what they called climates; which are a tract on the surface of the earth, of various breadths, being regulated by the different lengths of time be-

* The globe is not supposed in this case, or under this view of things, ever to be elevated above the limits of the sun's declination.

tween the riſing and ſetting of the ſun in the longeſt day, in different places.

From the equator to the latitude 66½ north and ſouth, a climate is conſtituted by the difference of half an hour in the length of the longeſt day, and this is ſufficient for underſtanding the ancients. Between the polar circle and the pole, the length of the longeſt day, in one parallel, exceeds the length of the longeſt in the next by a month; but of theſe the ancients knew nothing.

CLIMATES BETWEEN THE EQUATOR AND POLAR CIRCLES.

Climates.	Hours.	Latitude. D.	Latitude. M.	Breadth. D.	Breadth. M.	Climates.	Hours.	Latitude. D.	Latitude. M.	Breadth. D.	Breadth. M.
1	12½	8	25	8	25	13	18½	59	58	1	29
2	13	16	25	8	00	14	19	61	18	1	20
3	13½	23	50	7	25	15	19½	62	25	1	07
4	14	30	25	6	30	16	20	63	22	0	57
5	14½	36	28	6	08	17	20½	64	06	0	44
6	15	41	22	4	54	18	21	64	49	0	43
7	15½	45	29	4	07	19	21½	65	21	0	32
8	16	49	01	3	32	20	22	65	47	0	22
9	16½	52	00	2	57	21	22½	66	06	0	19
10	17	54	27	2	29	22	23	66	20	0	14
11	17½	56	37	2	10	23	23½	66	28	0	08
12	18	58	29	1	52	24	24	66	31	0	03

Therefore, to diſcover in what climate a place is, whoſe latitude does not exceed 66½ degrees, find the length of the longeſt day in that place, and ſubtracting 12 hours from that length, the number of half hours in the remainder will ſpecify the climate.

Problem xx.

To find the limits of the climates.

Elevate the north pole to 23° 28′, the ſun's declination on the longeſt day; and turn the globe eaſterly till the interſection of the meridian with the equator that paſſes through Libra comes to the horizon, and the hour of VI will then be under the meridian, which in this problem is the hour index, becauſe the ſun ſets this day at places on the equator as it does every day at VI o'clock. Now turn the globe eaſterly till the time under the meridian is 15 min. paſt VI. and you find that 8° 34′ of that graduated meridian is cut by the horizon; this is the beginning of the ſecond climate; and the limits of all the climates may be determined, by bringing ſucceſſively the time equal to half the length of the longeſt day under the meridian, and obſerving the degree of the graduated meridian cut by the horizon.

Zones.

Zones is another diviſion of the earth's ſurface uſed by the ancients: that part which the ſun paſſes over in a year, comprehending $23\frac{1}{2}$ degrees on each ſide the equator, was called by the ancients the torrid zone. The two frigid zones are contained between the polar circles. Between the torrid and the two frigid zones are contained the two temperate ones, each being about 43 degrees broad.

The latitude of a place being the mark of it's poſition with reſpect to the ſun, may be conſidered as a general index to the temperature of the climate : it is, however, liable to very great exceptions ; but to deny it abſolutely, would be to deny that the ſun is the ſource of light and heat below.

Nothing can be more hideous or mournful than the pictures which travellers preſent us of the polar regions. The ſeas, ſurrounding inhoſpitable coaſts, are covered with iſlands of ice, that have been increaſing for many centuries : ſome of theſe iſlands are immerſed ſix hundred feet under the ſurface of the ſea, and yet often rear up alſo their icy heads more than one hundred feet above it's level, and are three or four miles in circumference. The following account will give ſome idea of the ſcenery produced by arctic weather. At Smearingborough-Harbour, within fifteen degrees of the pole, the country is full of mountains, precipices, and rocks ; theſe are covered with ice and ſnow. In the vallies are hills of ice, which ſeem daily to accumulate. Theſe hills aſſume many ſtrange and fantaſtic appearances; ſome looking like churches or caſtles, ruins, ſhips in full ſail, whales, monſters, and all the various forms that fill the univerſe. There are ſeven of theſe ice-hills, which are the higheſt in the country. When the air is clear, and the light ſhines full upon them, the proſpect is inconceivably brilliant; the ſun is reflected from them as from glaſs; ſometimes they appear of a bright hue, like ſapphire; ſometimes variegated with all the glories of the priſmatic colours, exceeding, in the magnitude of luſtre, and beauty of colour, the richeſt gems in the world, diſpoſed in ſhapes wonderful to behold, dazzling the eye with the brilliancy of it's ſplendor. At Spitſbergen, within ten degrees of the pole, the earth is locked up in ice till the middle of May; in the beginning of July the plants are in flower, and perfect their ſeeds in a month's time: for though the ſun is much more oblique in the higher latitudes than with us, his long continuance above the horizon is attended with an accumulation of heat exceeding that of many places under the torrid zone; and there is reaſon to ſuppoſe, that the rays of the ſun, at any given altitude, produce greater degrees of heat in the condenſed air of the polar regions, than in the thinner air of this climate.

Yet, if we look for heat, and the remarkable effects of it, we muſt go to the countries near the equator, where we ſhall find a ſcenery totally different from that of the frigid zone. Here all things are upon a larger ſcale than in the temperate climates, their days are burning hot; in ſome parts their nights are piercing cold; their rains laſting and impetuous, like torrents; their dews exceſſive; their thunder and lightning more frequent, terrible, and dangerous; the heat burns up the lighter ſoil, and forms it into a ſandy deſert, while it quickens all the moiſter tracts with incredible vegetation.

The ancients ſuppoſed that the frigid zone was uninhabitable from cold, and the torrid from the intolerable heat of the ſun; we now, however, know that both are inhabited. The ſentiments of the ancients, therefore, in this reſpect, are a proof how inadequate the faculties of the human mind are to diſcuſſions of this nature, when unaſsiſted by facts.

Of the ancient Distinction of Places, by the Diversity of Shadows of upright Bodies at Noon.

When the ſun at noon is in the zenith of any place, the inhabitants of that place were by the ancients called *aſcii*, that is, without ſhadow; for the ſhadow of a man ſtanding upright, when the ſun is directly over his head, is not extended beyond that part of the earth which is directly under his body, and therefore will not be viſible.

As the ſhadow of every opake body is extended from the ſun, it follows, that when the ſun at noon is ſouthward from the zenith of any place, the ſhadow of an inhabitant of that place, and indeed of any other opake body, is extended towards the north.

But when the ſun is northward from the zenith of any place, the ſhadow falls towards the ſouth.

Thoſe are called *amphiſcii*, that have both kinds of meridian ſhadows.

Thoſe, whoſe meridian ſhadows are always projected one way, are termed *heteroſcii*.

PROBLEM XXI.

To illuſtrate the diſtinction of aſcii, amphiſcii, heteroſcii, and periſcii, by the globe.

Rectify the globe to the ſummer ſolſtice, and move the artificial horizon to the equator, the north point will be the moſt elevated at noon.

Which ſhews, that to thoſe inhabitants who live at the equator, the ſun will at this ſeaſon appear to the north at noon, and their ſhadow will therefore be projected ſouthwards.

But if you rectify the globe to the winter ſolſtice, the ſouth point being then the uppermoſt point at noon, the ſame perſons will at noon have the ſun on the ſouth ſide of them, and will project their ſhadows northwards.

Thus they are amphiſcii, projecting their ſhade both ways; which is the caſe of all the inhabitants within the tropics.

The artificial horizon remaining as before, rectify the globe to the times of the equinox, and you will find that when this horizon is under the ſtrong braſs meridian, a line going vertically upwards will be perpendicular to it, and conſequently the ſun will be directly over the heads of the inhabitants, and they will be aſcii, having no noon ſhade; their ſhadow is in the morning projected directly weſtward, in the evening directly eaſtward.

The ſame thing will alſo happen to all the inhabitants who live between the tropics of Cancer and Capricorn; ſo that they are not only aſcii, but amphiſcii alſo.

Thoſe who live without the tropics are heteroſcii; thoſe in north latitude have the noon ſhade always directed to the north, while thoſe in ſouth latitude have it always projected to the ſouth.

The inhabitants of the polar circles are called *periſcii;* becauſe, as the ſun goes round them continually, their ſhade goes round them likewiſe.

Of ancient Distinctions from Situation.

Theſe terms being often mentioned by ancient geographical writers to expreſs the different ſituation of parts of the globe, by the relation which the ſeveral inhabitants bore to one another, it will be neceſſary to take ſome notice of them.

The *antœci* are two nations which are in or near the ſame meridian; the one in north, the other in ſouth latitude.

They have therefore the ſame longitude, but not the ſame latitude; oppoſite ſeaſons of the year, but the ſame hour of the day; the days of the one are equal to the nights of the other, and, *vice verſa,* when the days of the one are at the longeſt, they are ſhorteſt at the other.

When they look towards each other, the ſun ſeems to riſe on the right hand of the one, but on the left of the other. They have different poles elevated; and the ſtars that never ſet to the one, are never ſeen by the other.

Periœci are alſo two oppoſite nations, ſituated on the ſame parallel of latitude.

They have therefore the ſame latitude, but differ 180 degrees in longitude; the ſame ſeasons of the year, but opposite hours of the day; for when it is twelve at night to the one, it is twelve at noon with the other. On the equinoctial days, the sun is rising to one, when it is setting to the other.

Antipodes are two nations diametrically, opposite, which have opposite seasons and latitude, opposite hours and longitude.

The sun and stars rise to the one, when they set to the other, and that during the whole year, for they have the same horizon.

The day of the one is the night of the other; and when the day is longest with the one, the other has it's shortest day.

They have the contrary seasons at the same time; different poles, but equally elevated; and those stars that are always above the horizon of one, are always under the horizon of the other.

PROBLEM XXII.

To find the Antœci, the Periœci, and the Antipodes of any place.

Bring the given place to the strong brass meridian, then in the opposite hemisphere, and under the same degree of latitude with the given place, you will find the antœci.

The given place remaining under the meridian, set the horary index to XII; then turn the globe, till the other XII is under the index, then will you find the perioeci under the same degree of latitude with the given place.

Thus the inhabitants of the south part of Chili are antoeci to the people of New England, whose Perioeci are those Tartars who dwell on the north borders of China, which Tartars have the said inhabitants of Chili for their antipodes.

This will become evident, by placing the globe in the position of a right sphere, and bringing those nations to the edge of the broad paper circle.

PROBLEM XXIII.

The day of the month being given, to find all those places on the globe, over whose zenith the sun will pass on that day.

Rectify the terrestrial globe, by bringing the given day of the month on the back side of the strong brass meridian, to coincide with the plane of the broad paper circle; observe the number of degrees of the brass meridian, which corresponds to the given day of the month.

This number of degrees, counted from the equator on the strong brass meridian, towards the elevated pole, is the point over which the sun is vertical; and all those places, which pass under this point, have the sun directly vertical on the given day.

Example. Bring the 11th of May to coincide with the plane of the broad paper circle, and the said plane will cut eighteen degrees for the elevation of the pole, which is equal to the sun's declination for that day, which being counted on the strong brass meridian towards the elevated pole, is the point over which the sun will be vertical; and all places that are under this degree, will have the sun on their zenith on the 11th of May.

Hence, when the sun's declination is equal to the latitude of any place in the torrid zone, the sun will be vertical to those inhabitants that day; which furnishes us with another method of solving this problem.

OF PROBLEMS PECULIAR TO THE SUN.

PROBLEM XXIV.

To find the sun's place on the broad paper circle.

Consider whether the year in which you seek the sun's place is bissextile, or whether it is the first, second, or third year after.

If it be the first year after bissextile, those divisions to which the numbers for the days of the months are affixed, are the divisions which are to be taken for the respective days of each month of that year at noon; opposite to which, in the circle of twelve signs, is the sun's place.

If it be the second year after bissextile, the first quarter of a day backwards, or towards the left hand, is the day of the month for that year, against which, as before, is the sun's place.

If it be the third year after bissextile, then three quarters of a day backwards is the day of the month for that year, opposite to which is the sun's place.

If the year in which you seek the sun's place be bissextile, then three quarters of a day backwards is the day of the month from the 1st of January to the 28th of February inclusive. The intercalary, or 29th day, is three-fourths of a day to the left hand from the 1st of March, and the 1st of March itself one quarter of a day forward, from the division marked I; and so for every day in the remaining part of the leap year; and opposite to these divisions is the sun's place.

In this manner the intercalary day is very well introduced every fourth year into the calendar, and the sun's place very nearly obtained, according to the Julian reckoning.

Thus,

A. D		Sun's place.	Apr. 25.	
1788	Bissextile - - . -	8	5°	35
1789	First year after - -	8	5	21
1790	Second - - -	8	5	6
1791	Third - - - -	8	4	55

Upon my father's globes there are twenty-three parallels, drawn at the distance of one degree from each other on both sides the equator, which, with two other parallels at 23½ degrees distance, include the ecliptic circle.

The two outermost circles are called the tropics; that on the north side the equator is called the tropic of Cancer, that which is on the south side, the tropic of Capricorn.

Now as the ecliptic is inclined to the equator, in an angle of 23½ degrees, and is included between the tropics, every parallel between these must cross the ecliptic in two points, which two points shew the sun's place when he is vertical to the inhabitants of that parallel; and the days of the month upon the broad paper circle answering to those points of the ecliptic, are the days on which the sun passes directly over their heads at noon, and which are sometimes called their two midsummer days.

It is usual to call the sun's diurnal paths parallels to the equator, which are therefore aptly represented by the above-mentioned parallel circle; though his path is properly a spiral line, which he is continually describing all the year appearing to move daily about a degree in the ecliptic.

PROBLEM XXV.

To find the sun's declination, and thence the parallel of latitude corresponding thereto.

Find the sun's place for the given day in the broad paper circle, by the preceeding problem, and seek that place in the ecliptic line upon the globe; this will shew the parallel of the sun's declination among the above-mentioned dotted lines, which is also the corresponding parallel of latitude; therefore all those places, through which this parallel passes, have the sun in their zenith at noon on the given day.

Thus on the 23d of May the sun's declination will be about 20 deg. 10 min.; and upon the 23d of August it will be 11 deg. 13 min. What has been said in the first part of this problem, will lead the reader to the solution of the following.

PROBLEM XXVI.

To find the two days on which the sun is in the zenith of any given place that is situated between the two tropics.

That parallel of declination, which passes through the given place, will cut the ecliptic line upon the globe in two points, which denote the sun's place, against which, on the broad paper circle, are the days and months required. Thus the sun is vertical at Barbadoes April 24, and August 18.

PROBLEM XXVII.

The day and hour at any place in the torrid zone being given, to find where the sun is vertical at that time.

Rectify the globe to the day of the month, and you have the sun's declination; bring the given place to the meridian, and set the hour index to XII; turn the globe till the index points to the given hour on the equator; then will the place be under the degree of the declination previously found.

Let the given place be London, and time the 11th day of May, at 4 min. past V in the afternoon; bring the 11th of May to coincide with the broad paper circle, and opposite to it you will find 18 degrees of north declination; as London is the given place, you have only to turn the globe till 4 min. past V westward of it is on the meridian, when you will find Port-Royal, in Jamaica, under the 18th degree of the meridian, which is the place where the sun is vertical at that time.

PROBLEM XXVIII.

The time of the day at any one place being given, to find all those places where at the same instant the sun is rising, setting, and on the meridian, and where he is vertical; likewise those places where it is midnight, twilight, and dark night; as well as those places in which the twilight is beginning and ending; and also to find the sun's altitude at any hour in the illuminated, and his depression in the obscure, hemisphere.

Rectify the globe to the day of the month, on the back side of the strong brass meridian, and the sun's declination for that day; bring the given place to the strong brass meridian, and set the horary index to XII upon the equator; turn the globe from west to east, until the horary index points to the given time. Then

All those places, which lie in the plane of the western side of the broad paper circle, see the sun rising, and at the same time those on the eastern side of it see him setting.

It is noon to all the inhabitants of those places under the upper half of the graduated side of the strong brass meridian, whilst at the same time those under the lower half have mid-night.

All those places which are between the upper surface of the broad paper circle, and the wire circle under it, are in the twilight, which begins to all those places on the western side that are immediately under the wire circle; it ends at all those which are in the plane of the paper circle.

The contrary happens on the eastern side; the twilight is just beginning to those places in which the sun is setting, and it's end is at the place just under the wire circle.

And those places which are under the twilight wire circle have dark night, unless the moon is favourable to them.

All places in the illuminated hemisphere have the sun's latitude equal to their distance from the edge of the enlightened disk, which is known by fixing the quadrant of altitude to the zenith, and laying it's graduated edge over any particular place.

The sun's depression is obtained in the same manner, by fixing the center of the quadrant at the nadir.

PROBLEM XXIX.

To find all those places within the polar circles on which the sun begins to shine, the time he shines constantly, when he begins to disappear, the length of his absence, as well as the first and last day of his appearance to those inhabitants; the day of the month, or latitude of the place being given.

Bring the given day of the month on the back side of the strong brass meridian to the plane of the broad paper circle; the sun is just then beginning to shine on all those places which are in the parallel that just touches the edge of the broad paper circle, and will for several days seem to skim all around, and but a little above their horizon, just as it appears to us at it's setting; but with this observable difference, that whereas our setting sun appears in one part of the horizon only, by them it is seen in every part thereof; from west to south, thence east to north, and so to west again.

Or if the latitude be given, elevate the globe to that latitude, and on the back of the strong brass meridian, opposite to the latitude, you obtain the day of the month; then all the other requisites are answered as above.

As the two concentric spaces, which contain the days of the month on the back side of the strong brass meridian, are graduated to shew the opposite days of the year, at 180 degrees distance; when the given day is brought to coincide with the broad paper circle, it shews when the sun begins to shine on that parallel, which is the first day of it's appearance above the horizon of that parallel.

And the plane of the broad paper circle cuts the day of the month on the opposite concentric space, when the sun begins to disappear to those inhabitants.

The length of the longest day is obtained by reckoning the number of days between the two opposite days found as above, and their difference from 365 gives the length of the longest night.

PROBLEM XXX.

To make use of the globe as a TELLURIAN, *or that kind of orrery which is chiefly intended to illustrate the phenomena that arise from the annual and diurnal motions of the earth.*

Describe a circle with chalk upon the floor, as large as the room will admit of, so that the globe may be moved round upon it; divide this circle into twelve parts, and mark them with the characters of the twelve signs, as they are engraved upon the broad paper circle; placing ♋ at the north, ♑ at the south, ♈ in the east, and ♎ in the west: the mariner's compass under the globe will direct the situation of these points, if the variation of the magnetic needle be attended to.

Note, At London the variation is between 23 and 24 degrees from the north-westward.

Elevate the north pole of the globe, so that 66½ degrees on the strong brass meridian may coincide with the surface of the broad paper circle, and this circle will then represent the plane of the ecliptic, or a plane coinciding with the earth's orbit.

Set a small table, or a stool, over the center of the chalked circle, to represent the sun, and place the terrestrial globe upon it's circumference over the point marked ♑, with the north pole facing the imaginary sun, and the north end of the needle pointing to the variation; and the globe will be in the position of the earth with respect to the sun at the time of the summer solstice, about the 21st of June; and the earth's axis, by this rectification of the globe, is inclined to the plane of the large chalked circle, as well as to the plane of the broad paper circle, in an angle of 66½ degrees; a line, or string, passing from the center of the imaginary sun to that of the globe, will represent a central solar ray connecting the centers of the earth and sun: this ray will fall upon the first point of Cancer, and describe that circle, shewing it to be the sun's place upon the terrestrial ecliptic, which is the same as if the sun's place, by extending the string, was referred to the opposite side of the chalked circle, here representing the earth's path in the heavens.

If we conceive a plane to pass through the center of the globe and the sun's center, it will also pass through the points of Cancer and Capricorn, in the terrestrial and celestial ecliptic; the central solar ray, in this position of the earth, is also in that plane: this can never happen but at the times of the solstice.

If another plane be conceived to pass through the center of the globe at right angles to the center solar ray, it will divide the globe into two hemispheres; that next the center of the chalked circle will represent the earth's illuminated disk, the contrary side of the same plane will at the same time shew the obscure hemisphere.

The reader may realize this second plane by cutting away a semicircle from a sheet of card paste board, with a radius of about 1½ tenth of an inch greater than that of the globe itself.*

If this plane be applied to 66½ degrees upon the strong brass meridian, it will be in the pole of the ecliptic; and in every situation of

* Or he may have a plane made of wood for this purpose

the globe round the circumference of the chalked circle, it will afford a lively and lasting idea of the various phenomena arising from the parallelism of the earth's axis, and in particular the daily change of the sun's declination, and the parallels thereby described.

Let the globe be removed from ♑ to ♒, and the needle pointing to the variation as before, will preserve the parallelism of the earth's axis; then it will be plain that the string, or central solar ray, will fall upon the first point of Leo, six signs distant from, but opposite to the sign ♒, upon which the globe stands; the central solar ray will now describe the 20th parallel of north declination, which will be about the 23d of July.

If the globe be moved in this manner from point to point round the circumference of the chalked circle, and care be taken at every removal that the north end of the magnetic needle, when settled, points to the degree of variation, the north pole of the globe will be observed to recede from the line connecting the centers of the earth and sun, until the globe is placed upon the point Cancer; after which, it will at every removal tend more and more towards the said line, till it comes to Capricorn again.

280

PROBLEM. XXXI.

To rectify either globe to the latitude and horizon of any place.

If the place be in north latitude, raise the north pole; if in south latitude, raise the south pole, until the degree of the given latitude, reckoned on the strong brass meridian under the elevated pole, cuts the plane of the broad paper circle; then this circle will represent the horizon of that place, while the place remains in the zenith, but no longer. This rectification is therefore unnatural, though it is the mode adopted in using the globes when mounted in the old manner.

PROBLEM XXXII.

To rectify for the sun's place.

After the former rectification, bring the degrees of the sun's place in the ecliptic line upon the globe to the strong brass meridian, and set the horary index to that XIIth hour upon the equator which is most elevated.

Or if the sun's place is to be retained, to answer various conclusions, bring the graduated edge of the moveable meridian to the degree of the sun's place in the ecliptic, and slide the wire which crosses the center of the artificial horizon thereto; then bring it's center, which is in the intersection of the aforesaid wire, and graduated edge of the moveable meridian, under the strong brass meridian as before, and set the horary index to that XII on the equator which is most elevated.

PROBLEM XXXIII.

To rectify for the zenith of any place.

After the first rectification, screw the nut of the quadrant of altitude so many degrees from the equator, reckoned on the strong brass meridian towards the elevated pole, as that pole is raised above the plane of the broad paper circle, and that point will represent the zenith of the place.

Note, The zenith and nadir are the poles of the horizon, the former being a point directly over our heads, and the latter, one directly under our feet.

If, when the globe is in this state, we look on the opposite side, the plane of the horizon will cut the strong brass meridian at the complement of the latitude, which is also the elevation of the equator above the horizon.

OF THE SOLUTION OF PROBLEMS, BY EXPOSING THE GLOBES TO THE SUN'S RAYS.

In the year 1679, *J. Moxon* published a treatise on what he called "*The English Globe;* being (says he) a stabil and immobil one, performing what the ordinary globes do, and much more; invented and described by the Right Hon. the *Earle of Castlemaine.*" This globe was designed to perform, by being merely exposed to the sun's rays, all those problems which in the usual way are solved by the adventitious aid of brazen meridians, hour indexes, &c.

My father thought that this method might be useful, to ground more deeply in the young pupil's mind, those principles which the globes are intended to explain; and by giving him a different view of the subject, improve and strengthen his mind; he therefore inserted on his globes some lines, for the purpose of solving a few problems in Lord Castlemaine's manner.

It appears to me, from a copy of Moxon's publication, which is in my possession, that the Earle of Castlemaine projected a new edition of his works, as the copy contains a great number of corrections, many alterations, and some additions. It is not very improbable, that at some future day I may re-publish this curious work, and adapt a small globe for the solution of the problems.

The meridians on our new terrestrial globes being secondaries to the equator, are also hour circles, and are marked as such with Roman figures, under the equator, and at the polar circles. But there is a difference in the figures placed to the same hour circle; if it cuts the IIId hour upon the polar circles, it will cut the IX hour upon the equator, which is six hours later, and so of all the rest.

Through the great Pacific sea, and the intersection of Libra, is drawn a broad meridian from pole to pole; it passes through the XIIth hour upon the equator, and the VIth hour upon each of the polar circles; this hour circle is graduated into degrees and parts, and numbered from the equator towards either pole.

There is another broad meridian passing through the Pacific sea, at the IXth hour upon the equator, and the IIId hour upon each polar circle; this contains only one quadrant, or 90 degrees; the numbers annexed to it begin at the northern polar circle, and end at the tropic of Capricorn.

Here we must likewise observe, there are 23 concentric circles drawn upon the terrestrial globe within the northern and southern polar circles, which for the future we shall call polar parallels; they are placed at the distance of one degree from each other, and represent the parallels of the sun's declination, but in a different manner from the 47 parallels between the tropics.

The following problems require the globe to be placed upon a plane that is level, or truly horizontal, which is easily attained, if the floor, pavement, gravel-walk in the garden, &c. should not happen to be horizontal.

A flat seasoned board, or any box which is about two feet broad, or two feet square, if the top be perfectly flat, will answer the purpose; the upper surface of either may be set truly horizontal, by the help of a pocket spirit level, or plumb rule, if you raise or depress this or that side by a wedge or two, as the spirit level shall direct; if you have a meridian line drawn on the place over which you substitute this horizontal plane, it may be readily transferred from thence to the surface just levelled; this being done, we are prepared for the solution of the following problems.

It will be necessary to define a term we are obliged to make use of in the solution of these problems, namely, the *shade of extuberancy:* by this is meant that shade which is caused by the sphericity of the globe, and answers to what we have heretofore named the terminator, defining the boundaries of the illuminated and obscure parts of the globe; this circle was, in the solution of some of the foregoing problems, represented by the broad paper circle, but is here realized by the rays of the sun.

PROBLEM XXXIV.

To observe the sun's altitude (by the terrestrial globe) when he shines bright, or when he can but just be discerned through a cloud.

Elevate the north pole of the globe to 66½ degrees; bring that meridian, or hour circle, which passes through the IXth hour upon the equator, under the graduated side of the strong brass meridian; the globe being now set upon the horizontal plane, turn it about thereon, frame and all, that the shadow of the strong brass meridian may fall directly under itself; or in other words, that the shade of it's graduated face may fall exactly upon the aforesaid hour circle; at that instant the shade of extuberancy will touch the true degree of the sun's altitude upon that meridian, which passes through the IXth hour upon the equator, reckoned from the polar circle, the most elevated part of which will then be in the zenith of the place where this operation is performed, and is the same whether it should happen to be either in north or south latitude.

Thus we may, in an easy and natural manner, obtain the altitude of the sun, at any time of the day, by the terrestrial globe; for it is very plain, when the sun rises, he brushes the zenith and nadir of the globe by his rays; and as he always illuminates half of it, (or a few minutes more, as his globe is considerably larger than that of the earth) therefore when the sun is risen a degree higher, he must necessarily illuminate a degree beyond the zenith, and so on proportionably from time to time.

But as the illuminated part is somewhat more than half, deduct 13 minutes from the shade of extuberancy, and you have the sun's altitude with tolerable exactness.

If you have any doubt how far the shade of extuberancy reaches, hold a pin, or your finger, on the globe, between the sun and point in dispute, and where the shade of either is lost, will be the point sought.

When the sun does not shine bright enough to cast a shadow.

Turn the meridian of the globe towards the sun, as before, or direct it so that it may lie in the same plane with it, which may be done if you have but the least glimpse of the sun through a cloud; hold a string in both hands, it having first been put between the strong brass meridian and the globe; stretch it at right angles to the meridian, and apply your face near to the globe, moving your eye lower and lower, till you can but just see the sun ; then bring the string held as before to this point upon the globe, that it may just obscure the sun from your sight, and the degree on the aforesaid hour circle, which the string then lies upon, will be the sun's altitude required, for his rays would shew the same point if he shone out bright.

Note. The moon's altitude may be observed by either of these methods, and the altitude of any star by the last of them.

PROBLEM XXXV.

To place the terrestrial globe in the sun's rays, that it may represent the natural position of the earth, either by a meridian line, or without it.

If you have a meridian line, set the north and south points of the broad paper circle directly over it, the north pole of the globe being elevated to the latitude of the place, and standing upon a level plane, bring the place you are in under the graduated side of the strong brass meridian, then the poles and parallel circles upon the globe will, without sensible error, correspond with those in the heavens, and each point, kingdom, and state, will be turned towards the real one which it represents.

If you have no meridian line, then the day of the month being known, find the sun's declination as before instructed, which will direct you to the parallel of the day, amongst the polar parallels, reckoned from either pole towards the polar circle; which you are to remember.

Set the globe upon your horizontal plane in the sun-shine, and put it nearly north and south by the mariner's compass, it being first elevated to the latitude of the place, and the place itself brought under the graduated side of the strong brass meridian; then move the frame and globe together, till the shade of extuberancy, or term of illumination, just touches the polar parallel for the day, and the globe will be settled as before; and if accurately performed, the variation of the magnetic needle will be shewn by the degree to which it points in the compass box.

And here observe, if the parallel for the day should not happen to fall on any one of those drawn upon the globe, you are to estimate a proportionable part between them, and reckon that the parallel of the day. If we had drawn more, the globe would have been confused.

The reason of this operation is, that as the sun illuminates half the globe, the shade of extuberancy will constantly be 90 degrees from the point wherein the sun is vertical.

If the sun be in the equator, the shade and illumination must terminate in the poles of the world; and when he is in any other diurnal parallel, the terms of illumination must fall short of, or go beyond either pole, as many degrees as the parallel which the sun describes that day is distant from the equator; therefore, when the shade of extuberancy touches the polar parallel for the day, the artificial globe will be in the same position, with respect to the sun, as the earth really is, and will be illuminated in the same manner.

PROBLEM XXXVI.

To find naturally the sun's declination, diurnal parallel, and his place thereon.

The globe being set upon an horizontal plane, and adjusted by a meridian line or otherwise, observe upon which, or between which polar parallel the term of illumination falls; it's distance from the pole is the degree of the sun's declination; reckon this distance from the equator among the larger parallels, and you have the parallel which the sun describes that day; upon which if you move a card, cut in the form of a double square, until it's shadow falls under itself, you will obtain the very place upon that parallel over which the sun is vertical at any hour of that day, if you set the place you are in under the graduated side of the strong brass meridian.

Note, The moon's declination, diurnal parallel, and place, may be found in the same manner. Likewise, when the sun does not shine bright, his declination, &c. may be found by an application in the manner of problem xxxiv.

PROBLEM XXXVII.

To find the sun's azimuth naturally.

If a great circle, at right angles to the horizon, passes through the zenith and nadir, and also through the sun's center, it's distance from the meridian in the morning or evening of any day, reckoned upon the degrees on the inner edge of the broad paper circle, will give the azimuth required.

Method 1.

Elevate either pole to the position of a parallel sphere, by bringing the north pole in north latitude, and the south pole in south latitude, into the zenith of the broad paper circle, having first placed the globe upon your meridian line, or by the other method before prescribed; hold up a plumb line, so that it may pass freely near the outward edge of the broad paper circle, and move it so that the shadow of the string may fall upon the elevated pole; then cast your eye immediately to it's shadow on the broad paper circle, and the degree it there falls upon is the sun's azimuth at that time, which may be reckoned from either the south or north points of the horizon.

Method II.

If you have only a glimpse, or faint sight of the sun, the globe being adjusted as before, stand on the shady side, and hold the plumb line on that side also, and move it till it cuts the sun's center, and the elevated pole at the same time; then cast your eye towards the broad paper circle, and the degree it there cuts is the sun's azimuth, which must be reckoned from the opposite cardinal point.

PROBLEM XXXVIII.

To shew that in some places of the earth's surface, the sun will be twice in the same azimuth in the morning, twice in the same azimuth in the afternoon: or in other words,

When the declination of the sun exceeds the latitude of any place, on either side of the equator, the sun will be on the same azimuth twice in the morning, and twice in the afternoon.

Thus, suppose the globe rectified to the latitude of Antigua, which is about 17 deg. of north latitude, and the sun to be in the beginning of Cancer, or to have the greatest north declination; set the quadrant of altitude to the 21st degree north of the east in the horizon, and turn the globe upon it's axis, the sun's center will be on that azimuth at 6 h. 30 min. and also at 10 h. 30 min. in the morning. At 8 h. 30 min. the sun will be as it were stationary, with respect to it's azimuth, for some time; as it will appear by placing the quadrant of altitude to the 17th degree north of the east in the horizon. If the quadrant be set to the same degrees north of the west, the sun's center will cross it twice as it approaches the horizon in the afternoon.

This appearance will happen more or less to all places situated in the torrid zone, whenever the sun's declination exceeds their latitude; and from hence we may infer, that the shadow of a dial, whose gnomon is erected perpendicular to an horizontal plane, must necessarily go back several degrees on the same day.

But as this can only happen within the torrid zone, and as Jerusalem lies about 8 degrees to the north of the tropic of Cancer, the retrocession of the shadow on the dial of Ahaz, at Jerusalem, was, in the strictest signification of the word, miraculous.

PROBLEM XXXIX.

To observe the hour of the day in the most natural manner, when the terrestrial globe is properly placed in the sun-shine.

There are many ways to perform this operation with respect to the hour, three of which are here inserted, being general to all the inhabitants of the earth; a fourth is added, peculiar to those of London, which will answer, without sensible error, at any place not exceeding the distance of 60 miles from this capital.

1*st*, *By a natural style.*

Having rectified the globe as before directed, and placed it upon an horizontal plane over your meridian line, or by the other method, hold a long pin upon the illuminated pole, in the direction of the polar axis, and it's shadow will shew the hour of the day amongst the polar parallels.

The axis of the globe being the common section of the hour circles, is in the plane of each; and as we suppose the globe to be properly adjusted, they will correspond with those in the heavens; therefore the shade of a pin, which is the axis continued, must fall upon the true hour circle.

2dly, By an artificial stile.

Tie a small string, with a noose, round the elevated pole, stretch it's other end beyond the globe, and move it so that the shadow of the string may fall upon the depressed axis; at that instant it's shadow upon the equator will give the solar hour to a minute.

But remember, that either the autumnal or vernal equinoctial colure must first be placed under the graduated side of the strong brass meridian, before you observe the hour, each of these being marked upon the equator with the hour XII.

The string in this last case being moved into the plane of the sun, corresponds with the true hour circle, and consequently gives the true hour.

3dly, Without any stile at all.

Every thing being rectified as before, look where the shade of extuberancy cuts the equator, the colure being under the graduated side of the strong brass meridian, and you obtain the hour in two places upon the equator, one of them going before, and the other following the sun.

Note, If this shade be dubious, apply a pin, or your finger, as before directed.

The reason is, that the shade of extuberancy being a great circle, cuts the equator in half, and the sun, in whatsoever parallel of declination he may happen to be, is always in the pole of the shade; consequently the confines of light and shade will shew the true hour of the day.

4thly, Peculiar to the inhabitants of London, and any place within the distance of sixty miles from it.

The globe being every way adjusted as before, and London brought under the graduated side of the strong brass meridian, hold up a plumb-line, so that it's shadow may fall upon the zenith point, (which in this case is London itself) and the shadow of the string will cut the parallel of the day upon that point to which the sun is then vertical, and that hour circle upon which this intersection falls, is the hour of the day; and as the meridians are drawn within the tropics, at twenty minutes distance from each other, the point cut by the intersection of the string upon the parallel of the day, being so near the equator, may, by a glance of the observer's eye, be referred thereto, and the true time obtained to a minute.

The plumb-line thus moved is the azimuth; which, by cutting the parallel of the day, gives the sun's place, and consequently the hour circle which intersects it.

From this last operation results a corollary, that gives a second way of rectifying the globe to the sun's rays.

If the azimuth and shade of the illuminated axis agree in the hour when the globe is rectified, then making them thus to agree, must rectify the globe.

COROLLARY.

Another method to rectify the globe to the sun's rays.

Move the globe, till the shadow of the plumb-line, which passes through the zenith cuts the same hour on the parallel of the day, that the shade of the pin, held in the direction of the axis, falls upon, amongst the polar parallels, and the globe is rectified.

The reason is, that the shadow of the axis represents an hour circle; and by it's agreement in the same hour, which the shadow of the azimuth string points out, by it's intersection on the parallel of the day, it shews the sun to be in the plane of the said parallel; which can never happen in the morning on the eastern side of the globe, nor in the evening on the western side of it, but when the globe is rectified.

This rectification of the globe is only placing it in such a manner, that the principal great circles and points may concur and fall in with those of the heavens.

The many advantages arising from these problems, relating to the placing of the globe in the sun's rays, the tutor will easily discern, and readily extend to his own, as well as to the benefit of his pupil.

THE

GENERAL PRINCIPLES

OF

DIALLING

ILLUSTRATED

BY THE TERRESTRIAL GLOBE.

THE art of dialling is of very ancient origin, and was in former times cultivated by all who had any pretensions to science; and before the invention of clocks and watches it was of the highest importance, and is even now used to correct and regulate them.

It teaches us, by means of the sun's rays, to divide time into equal parts, and to represent on any given surface the different circles into which, for convenience, we suppose the heavens to be divided, but principally the hour circles.

The hours are marked upon a plane, and pointed out by the interposition of a body which receiving the light of the sun, casts a shadow upon the plane. This body is called the axis, when it is parallel to the axis of the world. It is called the stile, when it is so placed that only the end of it coincides with the axis of the earth; in this case, it is only this point which marks the hours.

Among the various pleasing and profitable amusements which arise from the use of globes, that of dialling is not the least. By it the pupil will gain satisfactory ideas of the principles on which this branch of science is founded; and it will reward, with abundance of pleasure, those that chuse to exercise themselves in the practice of it.

If we imagine the hour circles of any place, as London, to be drawn upon the globe of the earth, and suppose this globe to be transparent, and to revolve round a real axis, which is opake, and casts a shadow; it is evident, that whenever the plane of any hour semicircle points at the sun, the shadow of the axis will fall upon the opposite semicircle.*

* Long's Astronomy, vol 1, page 82.

Let a P C p, fig. 1, plate XIII, represent a transparent globe; a b c d e f g the hour semicircles; it is clear, that if the semicircle P a p points at the sun, the shadow of the axis will fall upon the opposite semicircle.

If we imagine any plane to pass through the center of this transparent globe, the shadow of half the axis will always fall upon one side or the other of this intersecting plane.

Thus let A B C D be the plane of the horizon of London; so long as the sun is above the horizon, the shadow of the upper half of the axis will fall somewhere upon the upper side of the plane A B C D; when the sun is below the horizon of London, then the shadow of the lower half of the axis E falls upon the lower side of the plane.

When the plane of any hour semicircle points at the sun, the shadow of the axis marks the respective hour-line upon the intersecting plane. The hour-line is therefore a line drawn from the center of the intersecting plane, to that point where this plane is cut by the semicircle opposite to the hour semicircle.

Thus let A B C D, fig. 1, plate XIII, the horizon of London, be the intersecting plane; when the meridian of London points at the sun, as in the present figure, the shadow of the half axis P E falls upon the line E B, which is drawn from E, the center of the horizon, to the point where the horizon is cut by the opposite semicircle; therefore, E B is the line for the hour of twelve at noon.

By the same method the rest of the hour-lines are found, by drawing for every hour a line, from the center of the intersecting plane, to that semicircle which is opposite to the hour semicircle.

Thus fig. 2, plate XIII, shews the hour-lines drawn upon the plane of the horizon of London, with only so many hours as are necessary; that is, those hours, during which the sun is above the horizon of London, on the longest day in summer.

If, when the hour-lines are thus found, the semicircles be taken away, as the scaffolding is when the house is built, what remains, as in fig. 2, will be an *horizontal dial* for London.

If, instead of twelve hour circles, as above described, we take twice that number, we may by the points, where the intersecting plane is cut by them, find the lines for every half hour; if we take four times the number of hour circles, we may find the lines for every quarter of an hour, and so on progressively.

We have hitherto considered the horizon of London as the intersecting plane, by which is seen the method of making an horizontal dial. If we take any other plane for the intersecting plane, and find the points where the hour semicircles pass through it, and draw the lines from the center of the plane to those points, we shall have the hour-lines for that plane.

Fig. 3, plate XIII, shews how the hour-lines are found upon a south plane, perpendicular to the horizon. Fig. 4, shews a south dial, with it's hour-lines, without the semicircle, by means whereof they are found.

The *gnomon* of every sun-dial represents the axis of the earth, and is therefore always placed parallel to it; whether it be a wire, as in the figure before us, or the edge of a brass plate, as in a common horizontal dial.

The whole earth, as to it's bulk, is but a *point*, if compared to it's distance from the sun; therefore, if a small sphere of glass be placed on any part of the earth's surface, so that it's axis be parallel to the axis of the earth, and the sphere have such lines upon it, and such planes within it, as above described, it will shew the hour of the day as truly as if it were placed at the center of the earth, and the shell of the earth were as transparent as glass.

A wire sphere, with a thin flat plate of brass within it, is often made use of to explain the principles of dialling.

From what has been said, it is clear that dialling depends on finding where the shadow of a strait wire, parallel to the axis of the earth, will fall upon a given plane, every hour, half hour, &c. the hour-lines being found as above described, which we shall proceed to exemplify by the globe.

Every dial-plane (that is, the plane surface on which a dial is drawn) represents the plane of a great circle, which circle is an *horizon* to some country or other.

The center of the dial represents the center of the earth; and the gnomon which casts the shade represents the axis, and ought to point directly to the poles of the equator.

The plane upon which dials are delineated may be either, 1. parallel to the horizon; 2. perpendicular to the horizon; or, 3. cutting it at oblique angles.

PROBLEM. XL.

To construct an horizontal dial for any given latitude, by means of the terrestrial globe.

Elevate the globe to the latitude of the place, then bring the first meridian under the graduated edge of the strong brazen one, which will then be over the hour XII, or the equator. As our globes have meridians drawn through every fifteen degrees of the equator, these meridians will represent the true circles of the sphere, and will intersect the horizon of the globe, in certain points on each side of the meridian. The distance of these points from the meridian must be carefully noted down upon a piece of paper, as will be seen in the example. The pupil need not, however, take out into his table the distances further than from XII to VI, which is just 90 degrees; for the distances of XI, X, IX, VIII, VII, VI, in the forenoon, are the same from XII as the distances of I, II, III, IV, V, VI, in the afternoon; and these hour-lines continued through the center will give the opposite hour-lines on the other half of the dial.

No more hour-lines need be drawn than what answer to the sun's continuance above the horizon, on the longest day of the year, in the given latitude.

Example. Suppose the given place to be London, whose latitude is 51 deg. 30 min. north.

Elevate the north pole of the globe to 51½ degrees above the horizon; then will the axis of the globe have the same elevation above the broad paper circle, as the gnomon of the dial is to have above the plane thereof.

Turn the globe, till the first meridian (which on English globes passes through London) is under the graduated side of the strong brazen meridian; then observe and note the points where the hour-circles intersect the horizon; and as on our globes the inner graduated circle, on the broad paper circle, begins from the two sixes, or east and west, we shall begin from thence,

calling the hour - - -	VI	0°	0
we shall find the other hours intersecting the horizon at the following degrees:	V	18°	54
	IV	36	24
	III	51	57
	II	65	41
	I	78	9

which are the respective distances of the above hours from VI upon the plane of the horizon.

To transfer these, and the rest of the hours, upon an horizontal plane, draw the parallel right lines a c and b d, fig. 5, plate XIII, upon that plane, as far from each other as is equal to the intended thickness of the gnomon of the dial, and the space included between them will be the meridian, or twelve o'clock line upon the dial; cross this meridian at right angles by the line g h, which will be the six o'clock line; then setting one foot of your compasses in the intersection a, describe the quadrant g e with any convenient radius, or opening of the compasses; after this, set one foot of the compasses in the intersection b, as a center, and with the same radius describe the quadrant f h; then divide each quadrant into 90 equal parts, or degrees, as in the figure.

Because the hour-lines are less distant from each other about noon, than in any other part of the dial, it is best to have the centers of the quadrants at some distance from the center of the dial-plane, in order to enlarge the hour-distances near XII; thus the center of the plane is at A, but the center of the quadrants is at a and b.

Lay a rule over 78° 9′, and the center b, and draw there the hour-line of I. Through b, and 65 41, gives the hour-line of II. Through b, and 51 57, that of III. Through the same center, and 36 24, we obtain the hour-line of IV. And through it, and 18 54, that of V. And because the sun rises about four in the morning, continue the hour-lines of IV and V in the afternoon, through the center b to the opposite side of the dial.

Now lay a rule successively to the center a of the quadrant e g, and the like elevations or degrees of that quadrant, 78 9, 65 41, 51 57, 36 24, 18 54, which will give the forenoon hours of XI, X, IX, VIII, and VII; and because the sun does not set before VIII in the evening on the longest days, continue the hour-lines of VII and VIII in the afternoon, and all the hour lines will be finished on this dial.

Lastly, through $51\frac{1}{2}$ degrees on either quadrant, and from it's center, draw the right line a g for the axis of the gnomon a g i, and from g let fall the perpendicular g i upon the meridian line a i, and there will be a triangle made, whose sides are a g, g i, and i a; if a plate similar to this triangle be made as thick as the dis-

306

tance between the lines a c and b d, and be set upright between them, touching at a and b, the line a g will, when it is truly set, be parallel to the axis of the world, and will cast a shadow on the hour of the day.

The trouble of dividing the two quadrants may be saved, by using a line of chords, which is always placed upon every scale belonging to a case of instruments.

PROBLEM XLI.

To delineate a direct south dial for any given latitude, by the globe.

Let us suppose a south dial for the latitude of London.

Elevate the pole to the co-latitude of your place, and proceed in all respects as above taught for the horizontal dial, from VI in the morning to VI in the afternoon, only the hours must be reversed, as in fig. 3, plate XIII; and the hypothenuse a g of the gnomon a g f, must make an angle with the dial plane to the co-latitude of the place.

As the sun can shine no longer than from VI in the morning to VI in the evening, there is no occasion for having more than twelve hours upon this dial.

In solving this problem, we have considered our vertical south dial for the latitude of London, as an horizontal one for the complement of that latitude, or 38 deg. 30 min.; all direct vertical dials may be thus reduced to horizontal ones, in the same manner. The reason of this will be evident, if the globe be elevated to the latitude of London; for by fixing the quadrant of altitude to the zenith, and bringing it to intersect the horizon in the east point, it will point out the plane of the proposed dial.

This plane is at right angles to the meridian, and perpendicular to the horizon; and it is clear, from the bare inspection of the globe thus elevated, that it's axis forms an angle with this plane, which is just the complement of that which it forms with the horizon, and is therefore just equal to the co-latitude of the place; and that therefore it is most simple to rectify the globe to that co-latitude.

The north vertical dial is the same with the south, only the stile must point upwards, and that many of the hours from it's direction can be of no use.

PROBLEM XLII.

To make an erect dial, declining from the south towards the east or west.

Elevate the pole to the latitude of the place, and screw the quadrant of altitude to the zenith.

Then if your dial declines towards the east, (which we shall suppose in the present instance) count in the horizon the degrees of declination from the east point towards the north, and bring the lower end of the quadrant to coincide with that degree of declination at which the reckoning ends.

Then bring the first meridian under the graduated edge of the strong brass meridian, which strong meridian will be the horary index.

Now turn the globe westward, and observe the degrees cut in the quadrant of altitude by the first meridian, while the hours XI, X, IX, &c. in the forenoon, pass successively under the brazen one; and the degrees thus cut on the quadrant by the first meridian, are the respective distances of the forenoon hours, from XII, on the plane of the quadrant.

For the afternoon hours, turn the quadrant of altitude round the zenith, until it comes to the degree in the horizon, opposite to that where it was placed before, namely, as far from the west towards the south, and turn the globe eastward; and as the hours I, II, III, &c. pass under the strong brazen meridian, the first meridian will cut on the quadrant of altitude the number of degrees from the zenith, that each of the hours is from XII on the dial.

When the first meridian goes off the quadrant at the horizon, in the forenoon, the hour index will shew the time when the sun comes upon this dial; and when it goes off the quadrant in the afternoon, it points to the time when the sun leaves the dial.

Having thus found all the hour distances from XII, lay them down upon your dial plane, either by dividing a semicircle into two quadrants, or by the line of chords.

In all declining dials, the line on which the gnomon stands makes an angle with the twelve o'clock line, and falls among the forenoon hour lines, if the dial declines towards the east; and among the afternoon hour lines, when the dial declines towards the west; that is, to the left hand from the twelve o'clock line in the former case, and to the right hand from it in the latter.

To find the distance of this line from that of twelve.

This may be considered, 1. If the dial declines from the south towards the east, then count the degrees of that declination in the horizon, from the east point towards the north, and bring the lower end of the quadrant to that degree of declination where the reckoning ends; then turn the globe, until the first meridian cuts the horizon in the like number of degrees, counted from the south point towards the east, and the quadrant and first meridian will cross one another at right angles, and the number of degrees of the quadrant, which are intercepted between the first meridian and the zenith, is equal to the distance of this line from the twelve o'clock line.

The numbers of the first meridian, which are intercepted between the quadrant and the north pole, is equal to the elevation of the stile above the plane of the dial.

The second case is, when the dial declines westward from the south.

Count the declination from the east point of the horizon, towards the south, and bring the quadrant of altitude to the degree in the horizon, at which the reckoning ends, both for finding the forenoon hours, and the distance of the substile, or gnomon line, from the meridian; and for the afternoon hours, bring the quadrant to the opposite degrees in the horizon, namely, as far from the west towards the north, and then proceed in all respects as before.

It is presumed, that the foregoing instances will be sufficient to illustrate the general principles of dialling, and to give the pupil a general idea of that pleasing science; for accurate and expeditious methods of constructing dials, we must refer him to treatises written expressly on that subject.

NAVIGATION

EXPLAINED BY THE GLOBE.

NAVIGATION is the art of guiding a ship at sea, from one place to another, in the safest and most convenient manner. In order to attain this, four things are particularly necessary:

1. To know the situation and distance of places.

2. To know at all times the points of the compass.

3. To know the line which the ship is to be directed from one place to the other.

4. To know, in any part of the voyage, what point of the globe the ship is upon.

The knowledge of the distance and situation of places, between which a voyage is to be made, implies not only a general knowledge of geography, but of several other particulars, as the rocks, sands, streights, rivers, &c. near which we are to sail; the bending out, or running in of the shores, the knowledge of the times that particular winds sets in, the seasons when storms and hurricanes are to be expected, but especially the tides; these and many other similar circumstances are to be learned from sea charts, journals, &c. but chiefly by observation and experience.

The second particular to be attained, is the knowledge at all times of the points of the compass, where the ship is. The ancients, to whom the polarity of the loadstone was unknown, found in the day-time the east or west, by the rising or setting of the sun; and at night, the north by the polar star. We have the advantage of the mariner's compass, by which, at any time in the wide ocean, and the darkest night, we know where the north is, and consequently the rest of the points of the compass.

Indeed, before the invention of the mariner's compass, the voyages of the Europeans were principally confined to coasting; but this fortunate discovery has enabled the mariner to explore new seas, and discover new countries, which, without this valuable acquisition, would probably have remained for ever unknown.

The third thing required to be known, is the line which a ship describes upon the globe of the earth, in going from one place to another.

The shortest way from one place to another, is an arc of a great circle, drawn through the two places.

The most convenient way for a ship, is that by which we may sail from one place to another, directing the ship all the while towards the same point of the compass.

A ship is guided by steering or directing her towards some points of the compass; the line wherein a ship is directed, is called the ship's course, which is named from the point towards which she sails.

Thus if a ship sails towards the north-east point, her course is said to be N. E.

In long voyages, a ship's way may consist of a great number of different courses, as from A to B, from B to C, and from C to D, fig 9, plate XIII; when we speak of a ship's course, we consider one of these at a time; the seldomer the course is changed, the more easily the ship is directed.

If two places, A *and* Z, *fig.* 7, *plate* XIII. *lie under the same meridian*, the course from the one side to the other is due north or south. Thus let A Z be part of a meridian; if A be south of Z, the course from A to Z must be north, and the course from Z to A south. This is evident from the nature of a meridian, that it marks upon the horizon the north and south points, and that every point of any meridian is north or south from every other point of it. From hence we may deduce the following corollary; that if a ship sails due north or south, she will continue on the same meridian.

If two places lie under the equator, the course from one to the other is an arc of the equator, and is due east or west. Thus let a z, fig. 7, be a part of the equator; if a be west from z, the course from a to z is east, and the course from z to a is west: for since the equator marks the east and west points upon the horizon, every point of the equator lies east or west of every other point of it, as may be seen upon the globe, by placing it as for a right sphere, and bringing a or z, or any of the intermediate points, to the zenith; when it will be evident, that if we are to go from one of these points a, to the other z, or to any point on the equator, we must continue our course due east to arrive at a, or vice versa. From hence we may deduce this consequence, that if a ship under the equator sails due east or west, she will continue under the equator.

In the two foregoing cases, the course being an arc of a great circle, (the meridian or equator) is the shortest and the most convenient way it can sail.

If two places lie under the same parallel, the course from one to the other is due east or west; this may be seen upon the globe, by the following method: bring any point of a parallel to the zenith, and stretch a thread over it, perpendicular to the meridian; the thread will then be a tangent to the parallel, and stand east and west from the point of contact. Hence, If a ship sails in any parallel, due east or west, she will continue in the same parallel. In this case, the most convenient course, though not the shortest, from one to the other, is to sail due east or west.

If two places lie neither under the equator, nor on the same meridian, nor in the same parallel, the most convenient, though not the shortest, course from one to the other, is in a rhumb.

For if we should in this case attempt to go the shortest way, in a great circle drawn through the two places, we must be perpetually changing our course. Thus fig. 8, whatever is the bearing of Z from A, the bearings of all the intermediate points, as B, C, D, E, &c. will be different from it, as well as different from each other, as may be easily seen upon the globe, by bringing the first point A to the zenith, and observing the bearing of Z from each of them. Thus suppose, when the globe is rectified to the horizon of A, the bearing of Z from A be north-east, and the angle of position of Z, with regard to A, be 45 degrees; if we bring B to the zenith, we shall have a different horizon, and the bearing and angle of position from Z to B will be different from the former; and so on of the other points C, D, E, they will each of them have a different horizon, and Z will have a different bearing and angle of position.

From hence we may draw this corollary, that when two places lie one from the other, towards a point not cardinal, if we sail from one place towards the point of the other's bearing, we shall never arrive at the other place. Thus if Z lies north-east from A, if we sail from A towards the north-east, we shall never arrive at Z.

A *rhumb* upon the globe is a line drawn from a given place A, so as to cut all the meridians it passes through at equal angles; the rhumbs are denominated from the points of the compass, in a different manner from the winds. Thus, at sea, the north-east wind is that which blows from the north-east point of the horizon, towards the ship in which we are; but we are said to sail upon the N. E. rhumb, when we go towards the north-east.

The rhumb A B C D Z, fig. 8, plate XIII. passing through the meridians L M, N O, P Q, makes the angles L A B, N B C, P C D, equal; from whence it follows, that the direction of a rhumb is in every part of it towards the same point of the compass; thus from every point of a north-east rhumb upon the globe, the direction is towards the north-east, and that rhumb makes an angle of 45 deg. with every meridian it is drawn through.

Another property of the rhumbs is, that equal parts of the same rhumb are contained between parallels of equal distance of latitude; so that a ship continuing in the same rhumb, will run the same number of miles in sailing from the parallel of 10 to the parallel of 30, as she does in sailing from the parallel of 30 to that of 50.

The fourth thing mentioned to be required in navigation, was, to know at any time what point of the globe a ship is upon. This depends upon four things: 1. the longitude; 2. the latitude; 3. the course the ship has run; 4. the distance, that is, the way she has made, or the number of leagues or miles she has run in that course, from the place of the last observation. Now any two of these being known, the rest may be easily found.

Having thus given some general idea of navigation, we now proceed to the problems by which the cases of sailing are solved on the globe.

PROBLEM XLIII.

*Given the difference of latitude, and difference of longitude, to find the course and distance sailed.**

Example. Admit a ship sails from a port

* See Martin on the Globes.

A, in latitude 38 deg. to another port B, in latitude 5 deg. and finds her difference of longitude 43 deg.

Let the port A be brought to the meridian, and elevate the globe to the given latitude of that port 38 deg. and fixing the quadrant of altitude precisely over it on the meridian, move the quadrant to lie over the second port B, (found by the given difference of latitude and longitude) then will it cut in the horizon 50 deg. 45 min. for the angle of the *ship's course* to be steered from the port A. Also, count the degrees in the quadrant between the two ports, which you will find 51 deg.; this number multiplied by 60, (the nautical miles in a degree) will give 3060 for the distance run.

PROBLEM XLIV.

Given the difference of latitude and course, to find the difference of longitude and distance sailed.

Example. Admit a ship sails from a port A, in 25 deg. north latitude, to another port B, in 30 deg. south latitude, upon a course of 43 deg.

Bring the port A to the meridian, and rectify the globe to the latitude thereof 25 deg. where fix the quadrant of altitude, and place it so as to make an angle with the meridian of

43 deg. in the horizon, and observe where the edge of the quadrant intersects the parallel of 30 deg. south latitude, for that is the place of the port B. Then count the number of degrees on the edge of the quadrant intersected between the two ports, and there will be found 73 deg. which, multiplied by 60, gives 4380 miles for the distance sailed. As the two ports are now known, let each be brought to the meridian, and observe the difference of longitude in the equator respectively, which will be found 50 degrees.

N. B. Had this problem been solved by *loxodromics*, or sailing on a rhumb, the difference of longitude would then have been 52 deg. 30 min. between the two ports.

PROBLEM XLV.

Given the difference of latitude and distance run, to find the difference of longitude, and angle of the course.

Example. Admit a ship sails from a port A, in latitude 50 deg. to another port B, in latitude 17 deg. 30 min. and her distance run be 2220 miles. Rectify the globe to the latitude of the place A, then the distance run, reduced to degrees, will make 37 deg. which are to be reckoned from the end of the quadrant lying over the port A, under the meridian;

then is the quadrant to be moved, till the 37 deg. coincides with the parallel of 17 deg. 30 min. north latitude; then will the angle of the course appear in the arch of the horizon, intercepted between the quadrant and the meridian, which will be 32 deg. 40 min.; and by making a mark on the globe for the port B, and bringing the same to the meridian, you will observe what number of degrees pass under the meridian, which will be 20, the difference of longitude required.

PROBLEM XLVI.

Given the difference of longitude and course, to find the difference of latitude and distance sailed.

Example. Suppose a ship sails from A, in the latitude 51 deg. on a course making an angle with the meridian of 40 deg. till the difference of longitude be found just 20 deg.; then rectifying the globe to the latitude of the port A, place the quadrant of altitude so as to make an angle of 40 deg. with the meridian; then observe at what point it intersects the meridian passing through the given longitude of the port B, and there make a mark to represent the said port; then the number of degrees intercepted between that and the port A will be 28, which will give 1680 miles for the distance run. And the said mark for the port B, being brought to the meridian, will have it's latitude there shewn to be 27 deg. 40 min.

PROBLEM XLVII.

Given the course and distance sailed, to find the difference of longitude, and difference of latitude.

Example. Suppose a ship sails 1800 miles from a port A, 51 deg. 15 min, south-west, on an angle of 45 deg. to another port B.

Having rectified the globe to the port A, fix the quadrant of altitude over it in the zenith, and place it to the south-west point in the horizon; then upon the edge of the quadrant under 30 deg. (equal to 1800 miles from the port A) is the port B; which bring to the meridian, and you will there see the latitude; and at the same time, it's longitude on the equator, in the point cut by the meridian.

In all these cases, the ship is supposed to be kept upon the *arch of a great circle*, which is not difficult to be done, very nearly, by means of the globe, by frequently observing the latitude, measuring the distance sailed, and (when you can) finding the difference of longitude; for one of these being given, the place and course of the ship is known at the same time; and therefore the preceding course may be altered, and rectified without any trouble, through the whole voyage, as often as such observations can be obtained, or it is found necessary. Now if any of these *data* are but of the quantity of four or five degrees, it will suffice for correcting the ship's course by the globe, and carrying her directly to the intended port, according to the following problem.

PROBLEM XLVIII.

To steer a ship upon the arch of a great circle by the given difference of latitude, or difference of longitude, or distance sailed in a given time.

Admit a ship sails from a port A, to a very distant port Z, whose latitude and longitude are given, as well as it's geographical bearing from A; then,

First, having rectified the globe to the port A, lay the quadrant of altitude over the port Z, and draw thereby the arch of the great circle through A and Z; this will design the intended path or tract of the ship.

Secondly, having kept the ship upon the first given course for some time, suppose by an observation you find the latitude of the *present place* of the ship, this added to, or subducted from the latitude of the port A, will give the present latitude in the meridian; to which bring the path of the ship, and the part therein, which lies under the new latitude, is the true place B of the ship in the great arch. To the latitude of B rectify the globe, and lay the quadrant over Z, and it will shew in the horizon the new course to be steered.

Thirdly, suppose the ship to be steered upon this course, till her distance run be found 300 miles, or 5 deg.; then, the globe being rectified to the place B in the zenith, laying the quadrant from thence over the great arch, make a mark at the 5th degree from B, and that will be the present place of the ship, which call C; which being brought to the meridian, it's latitude and longitude will be known. Then rectify the globe to the place C, and laying the quadrant from thence to Z, the new course to be steered will appear in the horizon.

Fourthly, having steered some time upon this new course, suppose, by some means or other, you come to know the difference of longitude of the present place of the ship, and of any of the preceding places, C, B, A; as B, for instance; then bring B to the meridian, and turn the globe about, till so many degrees of the equator pass under the meridian as are equal to the discovered distance of longitude; then the point of the great arch cut by the meridian is the present place D of the ship, to which the new course is to be found as before.

And thus, by repeating these observations at proper intervals, you will find future places, E, F, G, &c. in the great arch; and by rectifying the course at each, your ship will be conducted on the great circle, or the nearest way from the port A to Z, by the *use of the globe* only.

OF THE USE

OF THE

TERRESTRIAL GLOBE,

WHEN MOUNTED

IN THE COMMON MANNER.

ALTHOUGH I have, in the first part of this essay, laid before my readers the reasons which induce me to prefer my father's manner of mounting the globes, to the old or Ptolemaic form, yet as many may be in possession of globes mounted in the old form, and others may have been taught by those globes, I thought it would render these essays more complete, to give an account of so many of the leading problems, solved on the common globes, as would enable them to apply the remainder of those heretofore solved, to their own use. This is the more expedient, as, since the publication of my father's treatise, there have been a few attempts to do away some of the inconveniences of the ancient form, particular that of the old hour-circle, which is now generally placed under the meridian.

I cannot, however, refrain from again observing to the pupil, that the solution of the problems on the old globes depends upon appearances; that therefore, if he means to content himself with the mere mechanical solution of them, the Ptolemaic globes will answer his purpose; but if he wishes to have clear ideas of the rationale of those problems, he must use those mounted in my father's manner.

The celestial globe is used the same way in both mountings, excepting that in my father's mounting it has some additional circles; but the difference is so trifling, that it is presumed the pupil can find no difficulty in applying the directions there given to the old form.

PROBLEM I.

To find the latitude and longitude of any given place on the globe.

Bring the place to the east side of the brass meridian, then the degree marked on the meridian over it shews it's latitude, and the degree of the equator under the meridian shews it's longitude.

Hence, if the longitude and latitude of any place be given, the place is easily found, by bringing the given longitude to the meridian; for then the place will lie under the given degree of latitude upon the meridian.

PROBLEM II.

To find the difference of longitude between any two given places.

Bring each of the given places successively to the brazen meridian, and see where the meridian cuts the equator each time; the number of degrees contained between those two points, if it be less than 180 deg. otherwise the remainder to 360 deg. will be the difference of longitude required.

PROBLEM III.

To rectify the globe for the latitude, zenith, and sun's place.

Find the latitude of the place by prob. 1, and if the place be in the northern hemisphere, elevate the north pole above the horizon, according to the latitude of the place. If the place be in the southern hemisphere, elevate the south pole above the south point of the horizon, as many degrees as are equal to the latitude.

Having elevated the globe according to it's latitude, count the degrees thereof upon the meridian from the equator towards the elevated pole, and that point will be the zenith, or the vertex of the place ; to this point of the meridian fasten the quadrant of altitude, so that the graduated edge thereof may be joined to the said point.

Having brought the sun's place in the ecliptic to the meridian, set the hour index to twelve at noon, and the globe will be rectified to the sun's place.

PROBLEM IV.

The hour of the day at any place being given, to find all those on the globe, where it is noon, midnight, or any given hour at that time.

On the globes when mounted in the common manner, it is now customary to place the hour-circle under the north pole; it is divided into twice twelve hours, and has two rows of figures, one running from east to west, the other from west to east; this circle is moveable, and the meridian answers the purpose of an index.

Bring the given place to the brazen meridian, and the given hour of the day on the hour-circle, this done, turn the globe about, till the meridian points at the hour desired; then, with all those under the meridian, it is noon, midnight, or any given hour at that time.

PROBLEM V.

The hour of the day at any place being given, to find the corresponding hour (or what o'clock it is at that time) in any other place.

Bring the given place to the brazen meridian, and set the hour-circle to the given time; then turn the globe about, until the place where the hour is required comes to the meridian, and the meridian will point out the hour of the day at that place.

Thus, when is is noon at London, it is

		H. M.	
At	Rome	0 52	P. M.
	Constantinople	2 7	P. M.
	Vera Cruz	5 30	A. M.
	Pekin in China	7 50	P. M.

PROBLEM VI.

The day of the month being given, to find all those places on the globe where the sun will be vertical, or in the zenith, that day.

Having found the sun's place in the ecliptic for the given day, bring the same to the brazen meridian, observe what degree of the meridian is over it, then turn the globe round it's axis, and all places that pass under that degree of the meridian, will have the sun vertical, or in the zenith, that day; *i. e.* directly over the head of each place at it's respective noon.

PROBLEM VII.

A place being given in the torrid zone, to find those two days in the year on which the sun will be vertical to that place.

Bring the given place to the brazen meridian, and mark the degree of latitude that is exactly over it on the meridian; then turn the globe about it's axis, and observe the two points of the ecliptic which pass exactly under that degree of latitude, and look on the horizon for the two days of the year in which the sun is in those points or degrees of the ecliptic, and they are the days required; for on them, and none else, the sun's declination is equal to the latitude of the given place.

PROBLEM. VIII.

To find the antœci, periœci, and antipodes of any given place.

Bring the given place to the brazen meridian, and having found it's latitude, keep the globe in that position, and count the same number of degrees of latitude on the meridian, from the equator towards the contrary pole, and where the reckoning ends, that will give the place of the antœci upon the globe. Those who live at the equator have no antœci.

The globe remaining in the same position, bring the upper XII on the horary circle to the meridian, then turn the globe about till the meridian points to the lower XII; the place which then lies under the meridian, having the same latitude with the given place, is the periœci required. Those who live at the poles, if any, have no periœci.

As the globe now stands (with the index at the lower XII), the antipodes of the given place are under the same point of the brazen meridian where it's antœci stood before.

PROBLEM. IX.

To find at what hour the sun rises and sets any day in the year, and also upon what point of the compass.

Rectify the globe for the latitude of the place you are in; bring the sun's place to the meridian, and bring the XII to the meridian; then turn the sun's place to the eastern edge of the horizon, and the meridian will point out the hour of rising; if you bring it to the western edge of the horizon, it will shew the setting.

Thus on the 16th day of March, the sun rose a little past six, and set a little before six.

Note. In the summer the sun rises and sets a little to the northward of the east and west points, but in winter, a little to the southward of them. If, therefore, when the sun's place is brought to the eastern and western edges of the horizon, you look on the inner circle, right against the sun's place, you will see the point of the compass upon which the sun rises and sets that day.

PROBLEM. X.

To find the length of the day and night at any time of the year.

Only double the time of the sun's rising that day, and it gives the length of the night; double the time of his setting, and it gives the length of the day.

This problem shews how long the sun stays with us any day, and how long he is absent from us any night.

Thus on the 26th of May the sun rises about four, and sets about eight; therefore the day is sixteen hours long, and the night eight.

PROBLEM XI.

To find the length of the longest or shortest day, at any place upon the earth.

Rectify the globe for that place, bring the beginning of Cancer to the meridian, bring XII to the meridian, then bring the same degree of Cancer to the east part of the horizon, and the meridian will shew the time of the sun's rising.

If the same degree be brought to the western side, the meridian will shew the setting, which doubled, (as in the last problem) will give the length of the longest day and shortest night.

If we bring the beginning of Capricorn to the meridian, and proceed in all respects as before, we shall have the length of the longest night and shortest day.

Thus in the Great Mogul's dominions, the longest day is fourteen hours, and the shortest night ten hours. The shortest day is ten hours, and the longest night fourteen hours.

At Petersburgh, the seat of the Empress of Russia, the longest day is about $19\frac{1}{2}$ hours, and the shortest night $4\frac{1}{2}$ hours; the shortest day $4\frac{1}{2}$ hours, and longest night $19\frac{1}{2}$ hours.

Note. In all places near the equator, the sun rises and sets at six the year round. From thence to the polar circles, the days increase as the latitude increases; so that at those circles themselves, the longest day is 24 hours, and the longest night just the same. From the polar circles to the poles, the days continue to lengthen into weeks and months; so that at the very pole, the sun shines for six months together in summer, and is absent from it six months in winter.

Note. That when it is summer with the northern inhabitants, it is winter with the southern, and the contrary; and every part of the world partakes of an equal share of light and darkness.

PROBLEM XII.

To find all those inhabitants to whom the sun is this moment rising or setting, in their meridian or midnight.

Find the sun's place in the ecliptic, and raise the pole as much above the horizon as the sun (that day) declines from the equator; then bring the place where the sun is vertical at that hour to the brass meridian; so it will then be in the zenith or center of the horizon. Now see what countries lie on the western edge of the horizon, for in them the sun is rising; to those on the eastern side he is setting; to those under the upper part of the meridian it is noon day; and to those under the lower part of it, it is midnight.

Thus on the 25th of April, at six o'clock in the evening, at Worcester,

The sun is rising at New Zealand; and to those who are sailing in the middle of the Great South Sea.

The sun is setting at Sweden, Hungary, Italy, Tunis, in the middle of Negroland and Guinea.

In the meridian (or noon) at the middle of Mexico, Bay of Honduras, middle of Florida, Canada, &c.

Midnight at the middle of Tartary, Bengal, India, and the seas near the Sunda isles.

PROBLEM XIII.

To find the beginning and end of twilight.

The twilight is that faint light which opens the morning by little and little in the east, before the sun rises; and gradually shuts in the evening in the west, after the sun is set. It arises from the sun's illuminating the upper part of the atmosphere, and begins always when he approaches within eighteen degrees of the eastern part of the horizon, and ends when he descends eighteen degrees below the western; when dark night commences, and continues till day breaks again.

To find the beginning of twilight, rectify the globe; turn the degree of the ecliptic, which is opposite to the sun's place, till it is elevated eighteen degrees in the quadrant of altitude above the horizon on the west, so will the index point the hour twilight begins.

This short specimen of problems by the old globes, it is presumed, will be sufficient to enable the pupil to solve any other.

PART IV.

OF THE USE OF THE CELESTIAL GLOBE.

THE celestial globe is an artificial representation of the heavens, having the fixed stars drawn upon it, in their natural order and situation; whilst it's rotation on it's axis represents the apparent diurnal motion of the sun, moon, and stars.

It is not known how early the ancients had any thing of this kind: we are not certain what the sphere of Atlas or Musæus was; perhaps Palamedes, who lived about the time of the Trojan war, had something of this kind; for of him it is said,

> To mark the signs that cloudless skies bestow,
> To tell the seasons, when to sail and plow,
> He first devised; each planet's order found,
> It's distance, period, in the blue profound.

From Pliny it would seem that Hipparchus had a celestial globe with the stars delineated upon it.

It is not to be supposed that the celestial globe is so just a representation of the heavens as the terrestrial globe is of the earth; because here the stars are drawn upon a convex surface, whereas they naturally appear in a concave one. But suppose the globe were made of glass, then to an eye placed in the center, the stars which are drawn upon it would appear in a concave surface, just as they do in the heavens.

Or if the reader was to suppose that holes were made in each star, and an eye placed in the center of the globe, it would view, through those holes, the same stars in the heavens that they represent.

As the terrestrial globe, by turning on it's axis, represents the *real diurnal motion* of the earth; so the celestial globe, by turning on it's axis, represents the *apparent diurnal motion* of the heavens.

For the sake of perspicuity, and to avoid continual references, it will be necessary to repeat here some articles which have been already mentioned.

The *ecliptic* is that graduated circle which crosses the equator in an angle of about 23½ degrees, and the angle is called the obliquity of the ecliptic.

This circle is divided into twelve equal parts, consisting of 30 degrees each; the beginnings of them are marked with characters, representing the twelve signs.

Aries ♈, Taurus ♉, Gemini ♊, Cancer ♋, Leo ♌, Virgo ♍, Libra ♎, Scorpio ♏, Sagittarius ♐, Capricornus ♑, Aquarius ♒, Pisces, ♓.

Upon my father's globes, just under the ecliptic, the months, and days of each month, are graduated, for the readier fixing the artificial sun upon it's place in the ecliptic.

The two points where the ecliptic crosses the equinoctial, (the circle that answers to the equator on the terrestrial globe) are called the *equinoctial points;* they are at the beginnings of Aries and Libra, and are so called, because when the sun is in either of them, the day and night is every where equal.

The first points of Cancer and Capricorn are called *solstitial points;* because when the sun arrives at either of them, he seems to stand in a manner still for several days, in respect to his distance from the equinoctial; when he is in one solstitial point, he makes to us the longest day; when in the other, the longest night.

The latitude and longitude of stars are determined from the ecliptic.

The *longitude* of the stars and planets is reckoned upon the ecliptic; the numbers beginning at the first points of Aries ♈, where the ecliptic crosses the equator, and increasing according to the order of the signs.

Thus suppose the sun to be in the 10th degree of Leo, we say, his longitude, or place, is four signs, ten degrees; because he has already passed the four signs, Aries, Taurus, Gemini, Cancer, and is ten degrees in the fifth.

The *latitude* of the stars and planets is determined by their distance from the ecliptic upon a secondary or great circle passing through it's poles, and crossing it at right angles.

Twenty-four of these circular lines, which cross the ecliptic at right angles, being fifteen degrees from each other, are drawn upon the surface of our celestial globe; which being produced both ways, those on one side meet in a point on the northern polar circle, and those on the other meet in a point on the southern polar circle.

The points determined by the meeting of these circles are called the poles of the ecliptic, one north, the other south.

From these definitions it follows, that longitude and latitude, on the celestial globe, bear just the same relation to the ecliptic, as they do on the terrestrial globe to the equator.

Thus as the longitude of places on the earth is measured by degrees upon the equator, counting from the first meridian; so the longitude of the heavenly bodies is measured by degrees upon the ecliptic, counting from the first point of Aries.

And as latitude on the earth is measured by degrees upon the meridian, counting from the equator; so the latitude of the heavenly bodies is measured by degrees upon a circle of longitude, counting either north or south from the ecliptic.

The sun, therefore, *has no latitude*, being always in the ecliptic; nor do we usually speak of his longitude, but rather of his place in the ecliptic, expressing it by such a degree and minute of such a sign, as 5 degrees of Taurus, instead of 35 degrees of longitude.

The distance of any heavenly body from the equinoctial, measured upon the meridian, is called it's *declination.*

Therefore, the sun's declination, north or south, at any time, is the same as the latitude of any place to which he is then vertical, which is never more than 23½ degrees.

Therefore all *parallels of declination* on the celestial globe are the very same as parallels of latitude on the terrestrial.

Stars may have north latitude and south declination, and vice versa.

That which is called longitude on the terrestrial globe, is called *right ascension* on the celestial; namely, the sun or star's distance from that meridian which passes through the first point of Aries, counted on the equinoctial.

Astronomers also speak of *oblique ascension* and *descension*, by which they mean the distance of that point of the equinoctial from the first point of Aries, which in an oblique sphere rises or sets, at the same time that the sun or star rises or sets.

Ascensional difference is the difference betwixt right and oblique ascension. The sun's ascensional difference turned into time, is just so much as he rises before or after six o'clock.

The celestial signs and constellations on the surface of the celestial globe, are represented by a variety of human and other figures, to which the stars that are either in or near them, are referred.

The several systems of stars, which are applied to those images, are called constellations. Twelve of these are represented on the ecliptic circle, and extend both northward and southward from it. So many of those stars as fall within the limits of 8 degrees on both sides of the ecliptic circle, together with such parts of their images as are contained within the aforesaid bounds, constitute a kind of broad hoop, belt, or girdle, which is called the *zodiac*.

The names and the respective characters of the twelve signs of the ecliptic may be learned by inspection on the surface of the broad paper circle, and the constellations from the globe itself.

The zodiac is represented by eight circles parallel to the ecliptic, on each side thereof; these circles are one degree distant from each other, so that the whole breadth of the zodiac is 16 degrees.

Amongst these parallels, the latitude of the planets is reckoned; and in their apparent motion they never exceed the limits of the zodiac.

On each side of the zodiac, as was observed, other constellations are distinguished; those on the north side are called northern, and those on the south side of it, southern constellations.

OF THE PRECESSION OF THE EQUINOXES.

All the stars which compose these constellations, are supposed to increase their longitude continually; upon which supposition, the whole starry firmament has a slow motion from west to east; insomuch that the first star in the constellation of Aries, which appeared in the vernal intersection of the equator and ecliptic in the time of Meton the Athenian, upwards of

1900 years ago, is now removed about 30 degrees from it.

This change of the stars in longitude, which has now become sufficiently apparent, is owing to a small retrograde motion of the equinoctial points, of about 50 seconds in a year, which is occasioned by the attraction of the sun and moon upon the protuberant matter about the equator. The same cause also occasions a small deviation in the parallelism of the earth's axis, by which it is continually directed towards different points in the heavens, and makes a complete revolution round the ecliptic in about 25,920 years. The former of these motions is called *the precession of the equinoxes*, the latter *the nutation of the earth's axis*. In consequence of this shifting of the equinoctial points, an alteration has taken place in the signs of the ecliptic; those stars, which in the infancy of astronomy were in Aries, being now got into Taurus, those of Taurus into Gemini, &c.; so that the stars which rose and set at any particular seasons of the year, in the times of Hesiod, Eudoxus, and Virgil, will not at present answer the descriptions given of them by those writers.

344

PROBLEM I.

To represent the motion of the equinoctial points backwards, or in antecedentia, upon the celestial globe, elevate the north pole so that it's axis may be perpendicular to the plane of the broad paper circle, and the equator will then be in the same plane; let these represent the ecliptic, and then the poles of the globe will also represent those of the ecliptic; the ecliptic line upon the globe will at the same time represent the equator, inclined in an angle of 23½ degrees to the broad paper circle, now called the ecliptic, and cutting it in two points, which are called the equinoctial intersections.

Now if you turn the globe slowly round upon it's axis from east to west, while it is in this position, these points of intersection will move round the same way; and the inclination of the circle, which in shewing this motion represents the equinoctial, will not be altered by such a revolution of the intersecting or equinoctial points. This motion is called the precession of the equinoxes, because it carries the equinoctial points backwards amongst the fixed stars.

The poles of the world seem to describe a circle from east to west, round the poles of the ecliptic, arising from the precession of the equinox. It is a very slow motion, for the equinoctial points take up 72 years to move one degree, and therefore they are 25,920 years in describing 360 degrees, or completing a revolution.

This motion of the poles is easily represented by the above described position of the globe, in which, if the reader remembers, the broad paper circle represents the ecliptic, and the axis of the globe being perpendicular thereto, represents the axis of the ecliptic; and the two points, where the circular lines meet, will represent the poles of the world, whence, as the globe is slowly turned from east to west, these points will revolve the same way about the poles of the globe, which are here supposed to represent the poles of the ecliptic. The axis of the world may revolve as above, although its situation, with respect to the ecliptic, be not altered; for the points here supposed to represent the poles of the world, will always keep the same distance from the broad paper circle, which represents the ecliptic in this situation of the globe.*

From the different degrees of brightness in the stars, some appear to be greater than others, or nearer to us; on our celestial globe they are distinguished into seven different magnitudes.

* Rutherforth's System of Nat. Philos. vol. ii. p. 730.

OF THE

USE OF THE CELESTIAL GLOBE,

IN THE SOLUTION OF

PROBLEMS RELATIVE TO THE SUN.

EVERY thing that relates to the sun is of such importance to man, that in all things he claims a natural preheminence. The sun is at once the most beautiful emblem of the Supreme Being, and, under his influence, the fostering parent of worlds; being present to them by his rays, cheering them by his countenance, cherishing them by his heat, adorning them at each returning spring with the gayest and richest attire, illuminating them with his light, and feeding the lamp of life.

To the ancients he was known under a variety of names, each characteristic of his different effects; he was their Hercules, the great deliverer, the restorer of light out of darkness, the dispenser of good, continually labouring for the happiness of a depraved race. He was the Mithra of the Persians, a word derived from love, or mercy, because the whole world is cherished by him, and feels as it were the effects of his love.

In the sacred scriptures, the original source of all emblematical writings, our Lord is called our sun, and the sun of righteousness; and as there is but one sun in the heavens, so there is but one true God, the maker and redeemer of all things, the light of the understanding, and the life of the soul.

As in scripture our God is spoken of as a shield and buckler, so the sun is characterized by this mark ⊙, representing a shield or buckler, the middle point, the umbo, or boss; because it is love, or life, which alone can protect from fear and death.

His celestial rays, like those of the sun, take their circuit round the earth; there is no corner of it so remote as to be without the reach of their vivifying and penetrating power. As the material light is always ready to run it's heavenly race, and daily issues forth with renewed vigour, like an invincible champion, still fresh to labour; so likewise did our *redeeming God* rejoice to run his glorious race, he excelled in strength, and triumphed, and continues to triumph over all the powers of darkness, and is ever manifesting himself as the deliverer, the protetor, the friend, and father, of the human race.*

* Horne on the Psalms.

PLOBLEM II.

To rectify the celestial globe.

To rectify the celestial globe, is to put it in that position in which it may represent exactly the apparent motion of the heavens.

In different places, the position will vary, and that according to the different latitude of the places. Therefore, to rectify for any place, find first, by the terrestrial globe, the latitude of that place.

The latitude of the place being found in degrees, elevate the pole of the celestial globe the same number of degrees and minutes above the plane of the horizon, for this is the name given to the broad paper circle, in the use of the celestial globe.

Thus the latitude of London being $51\frac{1}{2}$ degrees, let the globe be moved till the plane of the horizon cuts the meridian in that point.

The next rectification is for the sun's place, which may be performed as directed in prob. xxix; or look for the day of the month close under the ecliptic line, against which is the sun's place, place the artificial sun over that point, then bring the sun's place to the graduated edge of the strong brazen meridian, and set the hour index to the most elevated twelve.

Thus on the 24th of May the sun is in $3\frac{1}{2}$ degrees of Gemini, and is situated near the Bull's eye and the seven stars, which are not then visible, on account of his superior light. If the sun were on that day to suffer a total eclipse, these stars would then be seen shining with their accustomed brightness.

Lastly, set the meridian of the globe north and south, by the compass.

And the globe will be rectified, or put into a similar position, to the concave surface of the heavens, for the given latitude.

PROBLEM III.

To find the right ascension and declination of the sun for any day.

Bring the sun's place in the ecliptic for the given day to the meridian, and the degree of the meridian directly over it is the sun's declination for that day at noon. The point of the equinoctial cut by the meridian, when the sun's place is under it, will be the right ascension.

Thus April 19, the sun's declination is 11° 14′ north, his right ascension 27° 30′. On the 1st of December the sun's declination is 21° 54′ south, right ascension 247° 50′.

PROBLEM IV.

To find the sun's oblique ascension and descension, it's eastern and western amplitude, and time of rising and setting, on any given time, in any given place.

1. Rectify the globe for the latitude, the zenith, and the sun's place. 2. Bring the sun's place to the eastern side of the horizon; then the number of degrees intercepted between a degree of the equinoctial at the horizon and the beginning of Aries, is the sun's oblique ascension. 3. The number of degrees on the horizon intercepted between the east point and the sun's place, is the eastern or rising amplitude. 4. The hour shewn by the index is the time of sun-rising. 5. Carry the sun to the western side of the horizon, and you in the same manner obtain the oblique descension, western amplitude, and time of setting. Thus at London, May 1,

The sun's oblique ascension	18°	48′
Eastern amplitude	24	57 N
Time of rising -	4 h	40 m
Oblique descension	257°	7′
Western amplitude	26	9
Time of setting	7 h	4 m

PROBLEM V.

To find the sun's meridian altitude.

Rectify the globe for the latitude, zenith, and sun's place; and when the sun's place is in the meridian, the degrees between that point and the horizon are it's meridian altitude. Thus, on May 17, at London, the meridian altitude of the sun is 57° 55′.

PROBLEM VI.

To find the length of any day in the year, in any latitude, not exceeding 66^{1} *degrees.*

Elevate the celestial globe to the latitude, and set the center of the artificial sun to his place upon the ecliptic line on the globe for the given day, and bring it's center to the strong brass meridian, placing the horary index to that XII which is most elevated; then turn the globe till the artificial sun cuts the eastern edge of the horizon, and the horary index will shew the time of sun-rising; turn it to the western side, and you obtain the hour of sun-setting.

The length of the day and night will be obtained by doubling the time of sun-rising and setting, as before.

PROBLEM VII.

To find the length of the longest and shortest days in any latitude that does not exceed 66½ *degrees.*

Elevate the globe according to the latitude, and place the center of the artificial sun for the longest day upon the first point of Cancer, but for the shortest day upon the first point of Capricorn; then proceed as in the last problem.

But if the place hath south latitude, the sun is in the first point of Capricorn on their longest day, and in the first point of Cancer on their shortest day.

PROBLEM VIII.

To find the latitude of a place, in which it's longest day may be of any given length between twelve and twenty-four hours.

Set the artificial sun to the first point of Cancer, bring its center to the strong brass meridian, and set the horary index to XII; turn the globe till it points to half the number of the given hours and minutes; then elevate or depress the pole till the artificial sun coincides with the horizon, and that elevation of the pole is the latitude required.

PROBLEM IX.

To find the time of the sun's rising and setting, the length of the day and night, on any place whose latitude lies between the polar circles; and also the length of the shortest day in any of those latitudes, and in what climate they are.

Rectify the globe to the latitude of the given place, and bring the artificial sun to his place in the ecliptic for the given day of the month; and then bring it's center under the strong brass meridian, and set the horary index to that XII which is most elevated.

Then bring the center of the artificial sun to the eastern part of the broad paper circle, which in this case represents the horizon, and the horary index shews the time of the sun-rising; turn the artificial sun to the western side, and the horary index will shew the time of the sun-setting.

Double the time of sun-rising is the length of the night, and the double of that of sun-setting is the length of the day.

Thus, on the 5th day of June, the sun rises at 3 h. 40 min. and sets at 8 h. 20. min.; by doubling each number it will appear, that the length of this day is 16 h. 40. min. and that of the night 7 h. 20 min.

The longest day at all places in north latitude, is when the sun is in the first point of Cancer. And,

The longest day to those in south latitude, is when the sun is in the first point of Capricorn.

Wherefore, the globe being rectified as above, and the artificial sun placed to the first point of Cancer, and brought to the eastern edge of the broad paper circle, and the horary index being set to that XII which is most elevated, on turning the globe from east to west, until the artificial sun coincides with the western edge, the number of hours counted, which are passed over by the horary index, is the length of the longest day; their complement to twenty-four hours gives the length of the shortest night.

If twelve hours be subtracted from the length of the longest day, and the remaining hours doubled, you obtain the climate mentioned by ancient historians; and if you take half the climate, and add thereto twelve hours, you obtain the length of the longest day in that climate. This holds good for every climate between the polar circles.

A climate is a space upon the surface of the earth, contained between two parallels of latitude, so far distant from each other, that the longest day in one, differs half an hour from the longest day in the other parallel.

PROBLEM X.

The latitude of a place being given in one of the polar circles, (suppose the northern) to find what number of days (of 24 hours each) the sun doth constantly shine upon the same, how long he is absent, and also the first and last day of his appearance.

Having rectified the globe according to the latitude, turn it about until some point in the first quadrant of the ecliptic (because the latitude is north) intersects the meridian in the north point of the horizon; and right against that point of the ecliptic, on the horizon, stands the day of the month when the longest day begins.

And if the globe be turned about till some point in the second quadrant of the ecliptic cuts the meridian in the same point of the horizon, it will shew the sun's place when the longest day ends, whence the day of the month may be found, as before; then the number of natural days contained between the times the longest day begins and ends, is the length of the longest day required.

Again, turn the globe about, until some

point in the third quadrant of the ecliptic cuts the meridian in the south part of the horizon; that point of the ecliptic will give the time when the longest night begins.

Lastly, turn the globe about, until some point in the fourth quadrant of the ecliptic cuts the meridian in the south point of the horizon; and that point of the ecliptic will be the place of the sun when the longest night ends.

Or, the time when the longest day or night begins being known, their end may be found by counting the number of days from that time to the succeeding solstice; then counting the same number of days from the solstitial day, will give the time when it ends.

OF THE EQUATION OF TIME.

It is not possible, in a treatise of this kind, to enter into a disquisition of the nature of time. It is sufficient to observe, that if we would with exactness estimate the quantity of any portion of infinite duration, or convey an idea of the same to others, we make use of such known measures as have been originally borrowed from the motions of the heavenly bodies. It is true, none of these motions are exactly equal and uniform, but are subject to some small irregularities, which, though of no consequence in the affairs of civil life, must be taken into the account in astronomical calculations. There are other irregularities of more importance, one of which is in the inequality of the natural day.

It is a consideration that cannot be reflected upon without surprise, that wherever we look for commensurabilities and equalities in nature, we are always disappointed. The earth is spherical, but not perfectly so; the summer is unequal, when compared with the winter; the ecliptic disagrees with the equator, and never cuts it twice in the same equinoctial point. The orbit of the earth has an eccentricity more than double in proportion to the spheroidity of it's globe; no number of the revolutions of the moon coincides with any number of the revolutions of the earth in it's orbit; no two of the planets measure one another: and thus it is wherever we turn our thoughts, so different are the views of the Creator from our narrow conception of things; where we look for commensuration, we find variety and infinity.

Thus ancient astronomers looked upon the motion of the sun to be sufficiently regular for the mensuration of time; but, by the accurate observations of later astronomers, it is found that neither the days, nor even the hours, as measured by the sun's apparent motion, are of an equal length, on two accounts.

1st, A natural or solar day of 24 hours, is that space of time the sun takes up in passing from any particular meridian to the same again; but one revolution of the earth, with respect to a fixed star, is performed in 23 hours, 56 minutes, 4 seconds; therefore the unequal progression of the earth through her elliptical orbit, (as she takes almost eight days more to run through the northern half of the ecliptic, than she does to pass through the southern) is the reason that the length of the day is not exactly equal to the time in which the earth performs it's rotation about it's axis.

2dly, From the obliquity of the ecliptic to the equator, on which last we measure time; and as equal portions of one do not correspond to equal portions of the other, the apparent motion of the sun would not be uniform; or, in other words, those points of the equator which come to the meridian, with the place of the sun on different days, would not be at equal distances from each other.

PROBLEM XI.

To illustrate, by the globe, so much of the equation of time as is in consequence of the sun's apparent motion in the ecliptic.

Bring every tenth degree of the ecliptic to the graduated side of the strong brass meridian, and you will find that each tenth degree on the equator will not come thither with it; but in the following order from ♈ to ♋, every tenth degree of the ecliptic comes sooner to the strong brass meridian than their corresponding tenths on the equator; those in the second quadrant of the ecliptic, from ♋ to ♎, come later, from ♎ to ♑ sooner, and from ♑ to Aries later, whilst those at the beginning of each quadrant come to the meridian at the same time; therefore the sun and clock would be equal at these four times, if the sun was not longer in passing through one half of the ecliptic than the other, and the two inequalities joined together, compose that difference which is called the equation of time.

These causes are independent of each other, sometimes they agree, and at other times are contrary to one another.

The inequality of the natural day is the cause that clocks or watches are sometimes before, sometimes behind the sun.

A good and well regulated clock goes uniformly on throughout the year, so as to mark the equal hours of a natural day, of a mean length; a sun-dial marks the hours of every day in such a manner, that every hour is a 24th part of the time between the noon of that day, and the noon of the day immediately following. The time measured by a clock is called equal or true time, that measured by the sun-dial apparent time.

THE USE OF THE CELESTIAL GLOBE, IN PROBLEMS RELATIVE TO THE FIXED STARS.

The use of the celestial globe is in no instance more conspicuous, than in the problems concerning the fixed stars. Among many other advantages, it will, if joined with observations on the stars themselves, render the practice and theory of other problems easy and clear to the pupil, and vastly facilitate his progress in astronomical knowledge.

The heavens are as much studded over with stars in the day, as in the night; only they are then rendered invisible to us by the brightness of the solar rays. But when this glorious luminary descends below the horizon, they begin gradually to appear; when the sun is about twelve degrees below the horizon, stars of the first magnitude become visible; when he is thirteen degrees, those of the second are seen; when fourteen degrees, those of the third magnitude appear; when fifteen degrees, those of the fourth present themselves to view; when he is descended about eighteen degrees, the stars of the fifth and sixth magnitude, and those that are still smaller, become conspicuous, and the azure arch sparkles with all it's glory.

PROBLEM XII.

To find the right ascension and declination of any given star.

Bring the given star to the meridian, and the degree under which it lies is it's declination; and the point in which the meridian intersects the equinoctial is it's right ascension. Thus the right ascension of Sirius is 99°, it's declination 16° 25′ south; the right ascension of Arcturus is 211° 32′. it's declination 20° 20′ north.

The *declination* is used to find the latitude of places; the *right ascension* is used to find the time at which a star or planet comes to the meridian; to find at any given time how long it will be before any celestial body comes to the meridian; to determine in what order those bodies pass the meridian; and to make a catalogue of the fixed stars.

PROBLEM XIII.

To find the latitude and longitude of a given star.

Bring the pole of the ecliptic to the meridian, over which fix the quadrant of altitude, and, holding the globe very steady, move the quadrant to lie over the given star, and the degree on the quadrant cut by the star, is it's latitude; the degree of the ecliptic cut at the same time by the quadrant, is the longitude of the star.

Thus the latitude of *Arcturus* is 30° 30′; it's longitude 20° 20′ of Libra: the latitude of *Capella* is 22° 22′ north; it's longitude 18 8′ of Gemini.

The latitude and longitude of stars is used to fix precisely their place on the globe, to refer planets and comets to the stars, and, lastly, to determine whether they have any motion, whether any stars vanish, or new ones appear.

PROBLEM XIV.

The right ascension and declination of a star being given, to find it's place on the globe.

Turn the globe till the meridian cuts the equinoctial in the degree of right ascension.

Thus for example, suppose the right ascension of Aldebaran to be 65° 30′, and it's declination to be 16° north, then turn the globe about till the meridian cuts the equinoctial in 65° 30′, and under the 16° of the meridian, on the northern part, you will observe the star Aldebaran, or the bull's eye.

PROBLEM XV.

To find at what hour any known star passes the meridian, at any given day.

Find the sun's place for that day in the ecliptic, and bring it to the strong brass meridian, set the horary index to XII o'clock, then turn the globe till the star comes to the meridian, and the index will mark the time. Thus on the 15th of August, Lyra comes to the meridian at 45 min. past VIII in the evening. On the 14th of September the brightest of the Pleiades will be on the meridian at IV in the morning.

This problem is useful for directing when to look for any star on the meridian, in order to find the latitude of a place, to adjust a clock, &c.

PROBLEM XVI.

To find on what day a given star will come to the meridian, at any given hour.

Bring the given star to the meridian, and set the index to the proposed hour; then turn the globe till the index points to XII at noon, and observe the degree of the ecliptic then at the meridian; this is the sun's place, the day answering to which may be found on the calendar of the broad paper circle.

By knowing whether the hour be in the morning or afternoon, it will be easy to perceive which way to turn the globe, that the proper XII may be pointed to; the globe must be turned towards the west, if the given hour be in the morning, towards the east if it be afternoon.

Thus Arcturus will be on the meridian at III in the morning on March the 5th, and Cor Leonis at VIII in the evening on April the 21st.

PROBLEM XVII.

To represent the face of the heavens on the globe for a given hour on any day of the year, and learn to distinguish the visible fixed stars.

Rectify the globe to the given latitude of the place and day of the month, setting it due north and south by the needle; then turn the globe on it's axis till the index points to the given hour of the night; then all the upper hemisphere of the globe will represent the visible face of the heavens for that time, by which it will be easily seen what constellations and stars of note are then above our horizon, and what position they have with respect to the points of the compass. In this case, supposing the eye was placed in the center of the globe, and holes were pierced through the centers of the stars on it's surface, the eye would perceive through those holes the various corresponding stars in the firmament; and hence it would be easy to know the various constellations at sight, and to be able to call all the stars by their names.

Observe some star that you know, as one of the pointers in the Great Bear, or Sirius; find the same on the globe, and take notice of the position of the contiguous stars in the same or an adjoining constellation; direct your sight to the heavens, and you will see those stars in the same situation. Thus you may proceed from one constellation to another, till you are acquainted with most of the principal stars.

"For example: the situation of the stars at London on the 9th of February, at 2 min. past IX in the evening, is as follows.

"Sirius, or the Dog-star, is on the meridian, it's altitude 22°: Procyon, or the little Dog-star, 16° towards the east, it's altitude 43½: about 24° above this last, and something more towards the east, are the twins, Castor and Pollux: S.ó 5° E. and 35° in height, is the bright star Regulus, or Cor Leonis: exactly in the east and 22° high, is the star Deneb Alased in the Lion's tail: 30° from the east towards the north Arcturus is about 3 above the horizon: directly over Arcturus, and 31° above the horizon, is Cor Caroli: in the north-east are the stars in the extremity of the Great Bear's tail, Aleath the first star in the tail, and Dubhe the northernmost pointer in the same constellation; the altitude of the first of these is 30½, that of the second 41°, and that of the third 56°.

"Reckoning westward, we see the beautiful constellation Orion; the middle star of the three in his belt, is S. 20° W. it's altitude 35°: nine degrees below the belt, and a little more to the west, is Rigel the bright star in his heel: above his belt in a strait line drawn from Rigel between the middle and most northward in his belt, and 9° above it, is the bright star in his shoulder: S. 49° W. and 45½ above the horizon, is Aldebaran the southern eye of the Bull: a little to the west of Aldebaran, are the Hyades: the same altitude, and about S. 70° W, are the Pleiades: in the W. by *S.* point is Capella in Auriga, it's altitude 73°: in the north-west, and about 42° high, is the constellation Cassiopeia: and almost in the north, near the horizon, is the constellation Cygnus."*

PROBLEM XVIII.

To trace the circles of the sphere in the starry firmament.

I shall solve this problem for the time of the autumnal equinox; because that intersection of the equator and ecliptic will be directly under the depressed part of the meridian about midnight; and then the opposite intersection will be elevated above the horizon; and also because our first meridian upon the terrestrial globe passing through London, and the first point of Aries, when both globes are rectified to the latitude of London, and to the sun's place, and the first point of Aries is brought under the graduated side of each of their meridians, we shall have the corresponding face of the heavens and the earth represented, as they are with respect to each other at that time, and the principal circles of each sphere will correspond with each other.

The horizon is then distinguished, if we begin from the north, and count westward, by the following constellations; the hounds and waist of Bootes, the northern crown, the head of

* Bransby's Use of the Globes.

Hercules, the shoulders of Serpentarius, and Sobieski's shield; it passes a little below the feet of Antinous, and through those of Capricorn, through the Sculptor's frame, Eridanus, the star Rigel in Orion's foot, the head of Monoceros, the Crab, the head of the Little Lion, and lower part of the Great bear.

The meridian is then represented by the equinoctial colure, which passes through the star marked δ in the tail of the Little Bear, under the north pole, the pole star, one of the stars in the back of Cassiopeia's chair marked β, the head of Andromeda, the bright star in the wing of Pegasus marked γ, and the extremity of the tail of the whale.

That part of the equator which is then above the horizon, is distinguished on the western side by the northern part of Sobieski's shield, the shoulder of Antinous, the head and vessel of Aquarius, the belly of the western fish in Pisces; it passes through the head of the Whale, and a bright star marked λ in the corner of his mouth, and thence through the star marked δ in the belt of Orion, at that time near the eastern side of the horizon.

That half of the ecliptic which is then above the horizon, if we begin from the western side, presents to our view Capricornus, Aquarius, Pisces, Aries, Taurus, Gemini, and a part of the constellation Cancer.

The solstitial colure, from the western side, passes through Cerberus, and the hand of Hercules, thence by the western side of the constellation Lyra, and through the Dragon's head and body, through the pole point under the polar star, to the east of Auriga, through the star marked η in the foot of Castor, and through the hand and elbow of Orion.

The northern polar circle, from that part of the meridian under the elevated pole, advancing towards the west, passes through the shoulder of the Great Bear, thence a little to the north of the star marked α in the Dragon's tail, the great knot of the dragon, the middle of the body of Cepheus, the northern part of Cassiopeia, and base of her throne, through Camelopardalus, and the head of the Great Bear.

The tropic of Cancer, from the western edge of the horizon, passes under the arm of Hercules, under the Vulture, through the Goose and Fox, which is under the beak and wing of the Swan, under the star called Sheat, marked β in Pegasus, under the head of Andromeda, and through the star marked Φ in the fish of the constellation Pisces, above the bright star in the head of the Ram marked α, through the Pleiades, between the horns of the Bull, and through a group of stars at the foot of Castor, thence above a star marked δ, between Castor and Pollux, and so through a part of the constellation

Cancer, where it disappears by passing under the eastern part of the horizon.

The tropic of Capricorn, from the western side of the horizon, passes through the belly, and under the tail of Capricorn, thence under Aquarius, through a star in Eridanus marked c, thence under the belly of the Whale, through the base of the chemical Furnace, whence it goes under the Hare at the feet of Orion, being there depressed under the horizon.

The southern polar circle is invisible to the inhabitants of London, by being under our horizon.

Arctic and antarctic circles, or circles of perpetual apparition and occultation.

The largest parallel of latitude on the terrestrial globe, as well as the largest circle of declination on the celestial, that appears entire above the horizon of any place in north latitude, was called by the ancients the arctic circle, or circle of perpetual apparition.

Between the arctic circle and the north pole in the celestial sphere, are contained all those stars which never set at that place, and seem to us, by the rotative motion of the earth, to be perpetually carried round above our horizon, the circles parallel to the equator.

The largest parallel of latitude on the terrestrial, and the largest parallel of declination on the celestial globe, which is entirely hid below the horizon of any place, was by the ancients called the antarctic circle, or circle of perpetual occultation.

This circle includes all the stars which never rise in that place to an inhabitant of the northern hemisphere, but are perpetually below the horizon.

All arctic circles touch their horizons in the north point, and all antarctic circles touch their horizons in the south point; which point, in the terrestrial and celestial spheres, is the intersection of the meridian and horizon.

If the elevation of the pole be 45 degrees, the most elevated part either of the arctic or antarctic circle will be in the zenith of the place.

If the pole's elevation be less than 45 degrees, the zenith point of those places will fall without it's arctic or antarctic circle; if greater, it will fall within.

Therefore, the nearer any place is to the equator, the less will it's arctic and antarctic circles be; and on the contrary, the farther any place is from the equator, the greater they are. So that,

At the poles, the equator may be considered as both an arctic and antarctic circle, because it's plane is coincident with that of the horizon.

But at the equator (that is, in a right sphere) there is neither arctic nor antarctic circle.

They who live under the northern polar circle, have the tropic of Cancer for their arctic, and that of Capricorn for their antarctic circle.

And they who live on either tropic, have one of the polar circles for their arctic, and the other for their antarctic circle.

Hence, whether these circles fall within or without the tropics, their distance from the zenith of any place is ever equal to the difference between the pole's elevation, and that of the equator, above the horizon of that place.

From what has been said, it is plain there may be as many arctic and antarctic circles, as there are individual points upon any one meridian, between the north and south poles of the earth.

Many authors have mistaken these mutable circles, and have given their names to the immutable polar circles, which last are arctic and antarctic circles, in one particular case only, as has been shewn.

373

PROBLEM XIX.

To find the circle, or parallel of perpetual apparition, or occulation of a fixed star, in a given latitude.

By rectifying the globe to the latitude of the place, and turning it round on it's axis, it will be immediately evident, that the circle of perpetual apparition is that parallel of declination which is equal to the complement of the given latitude northward; and for the perpetual occultation, it is the same parallel southward; that is to say, in other words, all those stars, whose declinations exceed the co-latitude, will always be visible, or above the horizon; and all those in the opposite hemisphere, whose declination exceeds the co-latitude, never rise above the horizon.

For instance; in the latitude of London 51 deg. 30 min. whose co-latitude is 38 deg. 30 min. gives the parallels desired; for all those stars which are within the circle, towards the north pole, never descend below our horizon; and all those stars which are within the same circle, about the south pole, can never be seen in the latitude of London, as they never ascend above it's horizon.

OF PROBLEMS RELATING TO THE AZIMUTH, &c. OF THE SUN AND STARS.

PROBLEM XX.

The latitude of the place and the sun's place being given, to find the sun's amplitude.

That degree from east or west in the horizon, wherein any object rises or sets, is called the amplitude.

Rectify the globe, and bring the sun's place to the eastern side of the meridian, and the arch of the horizon intercepted between that point and the eastern point, will be the sun's amplitude at rising.

If the same point be brought to the western side of the horizon, the arch of the horizon intercepted between that point and the western point, will be the sun's amplitude at setting.

Thus on the 24th of May the sun rises at four, with 36 degrees of eastern amplitude, that is, 36 degrees from the east towards the north, and sets at eight, with 36 degrees of western amplitude.

The amplitude of the sun at rising and setting increases with the latitude of the place: and in very high northern latitudes, the sun scarce sets before he rises again. Homer had heard something of this, though it is not true of the Læstrygones, to whom he applies it.

Six days and nights a doubtful course we steer;
The next, proud LAMOS' lofty towers appear,
And Læstygonia's gates arise distinct in air.
The shepherd quitting here at night the plain,
Calls, to succeed his cares, the watchful swain.
But he that scorns the chains of sleep to wear,
And adds the herdsman's to the shepherd's care,
So near the pastures, and so short the way,
His double toils may claim a double pay,
And join the labours of the ngiht and day.

PROBLEM XXI.

To find the sun's altitude at any given time of the day.

Set the center of the artificial sun to his place in the ecliptic upon the globe, and rectify it to the latitude and zenith; bring the center of the artificial sun under the strong brass meridian, and set the hour index to that XII which is most elevated; turn the globe to the given hour, and move the graduated edge of the quadrant to the center of the artificial sun; and that degree on the quadrant, which is cut by the sun's center, is the sun's height at that time.

The artificial sun being brought under the strong brass meridian, and the quadrant laid upon it's center, will *shew it's meridian, or greatest altitude*, for that day.

If the sun be in the equator, his greatest or meridian altitude is equal to the elevation of the equator, which is always equal to the co-latitude of the place.

Thus on the 24th of May, at nine o'clock, the sun has 44 deg. altitude, and at six in the afternoon 20 deg.

OF THE AZIMUTHAL OR VERTICAL CIRCLES.

The vertical point, that is, the uppermost point of the celestial globe, represents a point in the heavens, directly over our heads, which is called our zenith.

From this point circular lines may be conceived crossing the horizon at right angles.

These are called *azimuth*, or *vertical circles*. That one which crosses the horizon at 10 deg. distance from the meridian on either side, is called an azimuth circle of 10 deg.; that which crosses at 20, is called an azimuth of 20 deg.

The azimuth of 90 deg. is called the *prime vertical:* it crosses the horizon at the eastern and western points.

Any *azimuth circle* may be represented by the graduated edge of the brass quadrant of altitude, when the center upon which it turns is screwed to that point of the strong brass meridian which answers to the latitude of the place, and the place is brought into the zenith.

If the said graduated edge should lie over the sun's center or place, at any given time, it will represent the sun's azimuth at that time.

If the graduated edge be fixed at any point, so as to represent any particular azimuth, and the sun's place be brought there, the horary index will shew at what time of that day the sun will be in that particular azimuth.

Here it may be observed, that the *amplitude* and azimuth are much the same.

The amplitude shewing the bearing of any object *when it rises or sets*, from the *east* and *west* points of the horizon.

The azimuth the bearing of any object when it is *above the horizon*, either from the *north* or *south* points thereof. These descriptions and illustrations being understood, we may proceed to

PROBLEM XXII.

To find at what time the sun is due east, the day and the latitude being given.

Rectify the globe; then if the latitude and declination are of one kind, bring the quadrant of altitude to the eastern point of the horizon, and the sun's place to the edge of the quadrant, and the index will shew the hour.

If the latitude and declination are of different kinds, bring the quadrant to the western point of the horizon, and the point in the ecliptic opposite to the sun's place to the edge of the quadrant, and then the index will shew the hour.

You will easily comprehend the reason of the foregoing distinction, because when the sun is in the equinoctial, it rises due east; but when it is in that part of the ecliptic which is towards the elevated pole, it rises before it is in the eastern vertical circle, and is therefore at that time *above* the horizon: whereas when it is in the other part of the ecliptic, it passes the eastern prime vertical before it rises, that is *below* the horizon; whence it is evident, that the opposite point of the ecliptic must then be in the west, and above the horizon. The sun is due east at London at 7 h. 6 min. on the 18th of May. The second of August, at Cape Horn, the sun is due east at 5 h. 10 min.

PROBLEM XXIII.

To find the rising, setting, and culminating of a star, it's continuance above the horizon, and it's oblique ascension and descension, and also it's eastern and western amplitude, for any given day and place.

1. Rectify the globe to the latitude and zenith, bring the sun's place for the day to the meridian, and set the hour index to XII. 2. Bring the star to the eastern side of the horizon, and it's eastern amplitude, oblique ascension, and time of rising, will be found as taught of the sun. 3. Carry the star to the western side of the horizon; and in the same manner it's western amplitude, oblique descension, and time of setting, will be found. 4. The time of rising, subtracted from that of setting, leaves the continuance of the star above the horizon. 5. This remainder, subtracted from 24 hours, gives the time of it's continuance below the horizon. 6. The hour to which the index points, when the star comes to the meridian, is the time of it's culminating or being on the meridian.

Let the given day be March 14, the place

London, the star Sirius; by working the problem, you will find

It rises at - -	2 h.	24 min. afternoon.
Culminates - -	6	57
Sets at - -	11	50
Is above the horizon	9	6

It's oblique ascension and descension are 120° 47′, and 77° 15′; it's amplitude 27°, southward.

PROBLEM XXIV.

The latitude, the altitude of the SUN *by day, or of a* STAR *by night, being given, to find the hour of the day, and the sun's or star's azimuth.*

Rectify the globe for the latitude, the zenith, and the sun's place, turn the globe and the quadrant of altitude, so that the sun's place, or the given star, may cut the given degree of altitude, the index will shew the hour, and the quadrant will be the azimuth in the horizon.

Thus on the 21st of August, at London, when the sun's altitude is 36° in the forenoon, the hour is IX, and the azimuth 58° from the south.

At Boston, December 8th, when Rigel had 15 of altitude, the hour was VIII, the azimuth S. E. by E. 7°.

PROBLEM XXV.

The latitude and hour of the day being given, to find the altitude and azimuth of the sun, or of a star.

Rectify the globe for the latitude, the zenith, and the sun's place, then the number of degrees contained betwixt the sun's place and the vertex is the sun's meridional zenith distance; the complement of which to 90 deg. is the sun's meridian altitude. If you turn the globe about until the index points to any other given hour, then bringing the quadrant of altitude to cut the sun's place, you will have the sun's altitude at that hour; and where the quadrant cuts the horizon, is the sun's azimuth at the same time. Thus May the 1st, at London, the sun's meridian altitude will be 53½ deg.; and at 10 o'clock in the morning, the sun's altitude will be 46 deg. and his azimuth about 44 deg. from the south part of the meridian. On the 2d of December, at Rome, at five in the morning, the altitude of Capella is 41 deg. 58 min. its azimuth 60 deg. 50 min. from N. to W.

382

PROBLEM XXVI.

The latitude of the place, and the day of the month being given, to find the depression of the sun below the horizon, and the azimuth, at any hour of the night.

Having rectified the globe for the latitude, the zenith, and the sun's place, take a point in the ecliptic exactly opposite to the sun's place, and find the sun's altitude and azimuth, as by the last problem, and these will be the depression and the altitude required.

Thus if the time given be the 1st of November, at 10 o'clock at night, the depression and azimuth will be the same as was found in the last problem.

PROBLEM XXVII.

The latitude, the sun's place, and his azimuth being given, to find his altitude, and the hour.

Rectify the globe for the latitude, the zenith, and the sun's place; then put the quadrant of altitude to the sun's azimuth in the horizon, and turn the globe till the sun's place meets the edge of the quadrant; then the said edge will shew the altitude, and the index point to the hour.

Thus, May 21st, at London, when the sun

is due east, his altitude will be about 24 deg. and the hour about VII in the morning; and when his azimuth is 60 degrees south-westerly, the altitude will be about 44½ degrees, and the hour II$\frac{5}{7}$ in the afternoon.

Thus the latitude and the day being known, and having besides either the altitude, the azimuth, or the hour, the other two may be easily found.

PROBLEM XXVIII.

The latitude of the place, and the azimuth of the sun or of a star being given, to find the hour of the day or night.

Rectify the globe for the latitude and sun's place, and bring the quadrant of altitude to the given azimuth in the horizon; turn the globe till the sun or star comes to the quadrant, and the index will shew the time. November 5, at Gibraltar, given the sun's azimuth 50 degrees from the south towards the east, the time you will find to be half past VIII in the morning. Given the azimuth of Vega at London, 57 deg. from the north towards the east, February the 8th, the time you will find twenty minutes past II in the morning.

But as it may possibly happen that we may see a star, and would be glad to know what star it is, or whether it may not be a new star, or a comet; how that may be discovered, will be seen under the following

PROBLEM XXIX.

The latitude of the place, the sun's place, the hour of the night, and the altitude and azimuth of any star being given, to find the star.

Rectifying the globe for the latitude of the place, and the sun's place; fix the quadrant of altitude in the zenith, and turn the globe till the hour index points to the given hour, and set the quadrant of altitude to the given azimuth; then the star that cuts the quadrant in the given altitude, will be the star sought.

Though two stars, that have different right ascensions, will not come to the meridian at the same time, yet it is possible that in a certain latitude they may come to the same vertical circle at the same time; and that consideration gives the following

PROBLEM XXX.

The latitude of the place, the sun's place, and two stars, that have the same azimuth, being given, to find the hour of the night.

Rectify the globe for the latitude, the zenith, and the sun's place; then turn the globe, and also the quadrant about, till both the stars coincide with it's edge; the hour index will shew the hour of the night, and the place where the quadrant cuts the horizon will be the common azimuth of both stars.

On the 15th of March, at London, the star Betelgeuſe, in the shoulder of Orion, and Regel, in the heel of Orion, were observed to have the same azimuth; on working the problem, you will find the time to be 8 hours 47 minutes.

What hath been observed above, of two stars that have the same azimuth, will hold good likewise of two stars that have the same altitude; from whence we have the following

PROBLEM XXXI.

The latitude of the place, the sun's place, and two stars, that have the same altitude, being given, to find the hour of the night.

Rectify the globe for the latitude of the place, the zenith, and the sun's place; turn the globe, so that the same degree on the quadrant shall cut both the stars, then the hour index will shew the hour of the night.

In the former propositions, the latitude of the place is supposed to be given, or known; but as it is frequently necessary to find the latitude of the place, especially at sea, how this may be found, in a rude manner at least, having the time given by a good clock, or watch, will be seen in the following.

PROBLEM XXXII.

The suns's place, the hour of the night, and two stars, that have the same azimuth, or altitude, being given, to find the latitude of the place.

Rectify the globe for the sun's place, and turn it till the index points to the given hour of the night; keep the globe from turning, and move it up and down in the notches, till the two given stars have the same azimuth, or altitude; then the brass meridian will shew the height of the pole, and consequently the latitude of the place.

PROBLEM XXXII.

Two stars being given, one on the meridian, and the other on the east and west part of the horizon, to find the latitude of the place.

Bring the star observed on the meridian to the meridian of the globe; then keeping the globe from turning round it's axis, slide the meridian up or down in the notches, till the other star is brought to the east or west part of the horizon, and that elevation of the pole will be the latitude of the place sought.

OBSERVATION.

From what hath been said, it appears, that of these five things, 1. the latitude of the place; 2. the sun's place in the ecliptic; 3. the hour of the night; 4. the common azimuth of two known fixed stars; 5. the equal altitude of two known fixed stars; any *three* of them being given, the remaining *two* will easily be found.

There are three sorts of risings and settings of the fixed stars, taken notice of by ancient authors, and commonly called *poetial risings* and *settings*, because mostly taken notice of by the poets.

These are the *cosmical*, *achronical*, and *heliacal*.*

They are to be found in most authors that treat on the doctrine of the sphere, and are now chiefly useful in comparing and understanding passages in the ancient writers; such are Hesiod, Virgil, Columella, Ovid, Pliny, &c. How they are to be found by calculation, may be seen in Petavius's Uranologion, and Dr. Gregory's Astronomy.

DEFINITION.

When a star rises or sets at sun-rising, it is said to rise or set COSMICALLY.

From whence we shall have the following

* Costard's History of Astronomy.

PROBLEM XXXIV.

The latitude of the place being given, to find, by the globe, the time of the year when a given star rises or sets cosmically.

Let the given place be Rome, whose latitude is 42 deg. 8 min. north; and let the given star be the Lucida Pleiadum. Rectify the globe for the latitude of the place; bring the star to the edge of the eastern horizon, and mark the point of the ecliptic rising along with it; that will be found to be Taurus, 18 deg. opposite to which, on the horizon, will be found May the 8th. The Lucida Pleiadum, therefore, rises cosmically May the 8th.

If the globe continues rectified as before, and the Lucida Pleiadum be brought to the edge of the western horizon, the point of the ecliptic, which is the sun's place, then rising on the eastern side of the horizon, will be Scorpio, 29 deg. opposite to which, on the horizon, will be found November the 21st. The Lucida Pleiadum, therefore, sets cosmically November the 21st.

In the same manner, in the latitude of London, Sirius will be found to rise cosmically August the 10th, and to set cosmically November the 10th.

It is of the cosmical setting of the Pleiades, that Virgil is to be understood in this line,

*Ante tibi Eoæ Atlantides abscondantur,**

and not of their *setting in the east*, as some have imagined, where stars rise, but never set.

DEFINITION.

When a star rises or sets at sun-setting, it is said to rise or set ACHRONICALLY.

Hence, likewise, we have the following

PROBLEM. XXXV.

The latitude of the place being given, to find the time of the year when a given star will rise or set achronically.

Let the given place be Athens, whose latitude is 37 deg. north, and let the given star be Arcturus.

Rectify the globe for the latitude of the place, and bringing Arcturus to the eastern side of the horizon, mark the point of the ecliptic then setting on the western side; that will be found Aries, 12 deg. opposite to which, on the horizon, will be found April the 2d. Therefore Arcturus rises at Athens achronically April the 2d.

It is of this rising of Arcturus that Hesiod speaks in his Opera and Dies.†

When from the solstice sixty wint'ry days
Their turns have finish'd, mark, with glitt'ring rays,
From ocean's sacred flood, *Arcturus* rise,
Then first to gild the dusky evening skies.

* Georg. l. 1. v. 221. † Lib. ii. ver. 285.

If the globe continues rectified to the latitude of the place, as before, and Arcturus be brought to the western side of the horizon, the point of the ecliptic setting along with it will be Sagittary, 7 deg. opposite to which, on the horizon, will be found November the 29th. At Athens, therefore, Arcturus sets achronically November the 29th.

In the same manner Aldebaran, or the Bull's eye, will be found to rise achronically May the 22d, and to set achronically December the 19th.

DEFINITION.

When a star first becomes visible in a morning, after it hath been so near the sun as to be hid by the splendor of his rays, it is said to rise HELIACALLY.

But for this there is required some certain depression of the sun below the horizon, more or less according to the magnitude of the star. A star of the first magnitude is commonly supposed to require that the sun be depressed 12 deg. perpendicularly below the horizon.

This being premised, we have the following

PROBLEM XXXVI.

The latitude of the place being given, to find the time of the year when a given star will rise heliacally.

Let the given place be Rome, whose latitude is 42 deg. north, and let the given star be the bright star in the Bull's horn.

Rectify the globe for the latitude of the place, screw on the brass quadrant of altitude in it's zenith, and turn it to the western side of the horizon. Bring the star to the eastern side of the horizon, and mark what degree of the ecliptic is cut by 12 deg. marked on the quadrant of altitude; that will be found to be Capricorn, 3 deg. the point opposite to which is Cancer, 3 deg. and opposite to this will be found on the horizon, June 25th. The bright star, therefore, in the Bull's horn, in the latitude of Rome, rises heliacally June the 25th.

These kinds of risings and settings are not only mentioned by the poets, but likewise by the ancient physicians and historians.

Thus Hippocrates, in his book De Ære, says, "One ought to observe the heliacal risings and settings of the stars, especially the *Dog-star*, and *Arcturus*; likewise the *cosmical* setting of the *Pleiades*."

And Polybius, speaking of the loss of the

Roman fleet, in the first Punic war, says, "It was not so much owing to fortune, as to the obstinacy of the consuls, in not hearkening to their pilots, who dissuaded them from putting to sea, at that season of the year, which was between the rising of *Orion* and the *Dog-star;* it being always dangerous, and subject to storms."*

DEFINITION.

When a star is first immersed in the evening, or hid by the sun's rays, it is said to set HELIACALLY.

And this again is said to be, when a star of the first magnitude comes within twelve degrees of the sun, reckoned in the perpendicular.

Hence again we have the following

PROBLEM XXXVII.

The latitude of the place being given, to find the time of the year when a given star sets heliacally.

Let the given place be Rome, in latitude 42 deg. north, and let the given star be the bright star in the Bull's horn. Rectify the globe for the latitude of the place, and bring the star

* Lib. i. p. 53.

to the edge of the western horizon; turn the quadrant of altitude, till 12 deg. cut the ecliptic on the eastern side of the meridian. This will be found to be 7 deg. of Sagittary, the point opposite to which, in the ecliptic, is 7 deg. of Gemini; and opposite to that, on the horizon, is May the 28th, the time of the year when that sets heliacally in the latitude of Rome.

OF THE CORRESPONDENCE OF THE CELESTIAL AND TERRESTRIAL SPHERES.

That the reader may thoroughly understand what is meant by the correspondence between the two spheres, let him imagine the celestial globe to be delineated upon glass, or any other transparent matter, which shall invest or surround the terrestrial globe, but in such a manner, that either may be turned about upon the poles of the globe, while the other remains fixed; and suppose the first point of Aries, on the investing globe, to be placed on the first point of Aries on the terrestrial globe, (which point is in the meridian of London), then every star in the celestial sphere will be directly over those places to which it is a correspondent. Each star will then have the degree of it's right ascension directly upon the corresponding degree of terrestrial longitude; their declination will also be the same with the latitude of the places to which they answer; or, in other words, when the declination of a star is equal to the latitude of a place, such star, within the space of 24 hours, will pass vertically over that place and all others that have the same latitude.

If we conceive the celestial investing globe to to be fixed, and the terrestrial globe to be gradually turned from west to east, it is clear, that as the meridian of London passes from one degree to another under the investing sphere, every star in the celestial sphere becomes correspondent to another place upon the earth, and so on, until the earth has completed one diurnal revolution; or till all the stars, by their apparent daily motion, have passed over every meridian of the terrestrial globe. From this view of the subject, an amazing variety, uniting in wonderful and astonishing harmony, presents itself to the attentive reader; and future ages will find it difficult to investigate the reasons that should induce the present race of astronomers to neglect a subject so highly interesting to science, even in a practical view, but which in theory would lead them into more sublime speculations, than any that ever yet presented themselves to their minds.

A GENERAL DESCRIPTION OF THE PASSAGE OF THE STAR MARKED γ IN THE HEAD OF THE CONSTELLATION DRACO, OVER THE PARALLEL OF LONDON.

The star γ, in the head of the constellation Draco, having 51 deg. 32 min. north declination, equal to the latitude of London, is the correspondent star thereto. To find the places which it passes over, bring London to the graduated side of the brass meridian, and you will find that the degree of the meridian over London, and the representative of the star, passes over from London, the road to Bristol, crosses the Severn, the Bristol channel, the counties of Cork and Kerry in Ireland, the north part of the Atlantic ocean, the streights of Belleisle, New Britain, the north part of the province of Canada, New South Wales, the southern part of Kamschatka, thence over different Tartarian nations, several provinces of Russia, over Poland, part of Germany, the southern part of the United Provinces, when, crossing the sea, it arrives again at the meridian of London.

When the said star, or any other star, is on the meridian of London, or any other meridian, all other stars, according to their declination and right ascension, and difference of right ascension, (which answers to terrestrial latitude, longitude, and difference of longitude) will at the same time be on such meridians, and vertical to such places as correspond in latitude, longitude, and difference of longitude, with the declination, &c. of the respective stars.*

From the stars, therefore, thus considered, we attain a copious field of geographical knowledge, and may gain a clear idea of the proportionable distances and real bearings, of remote empires, kingdoms, and provinces, from our own zenith, at the same instant of time; which may be found in the same manner as we found the place to which the sun was vertical at any proposed time.

Many instances of this mode of attaining geographical knowledge, may be found in my father's treatise on the globes.

OF THE USE OF THE CELESTIAL GLOBE, IN PROBLEMS RELATIVE TO THE PLANETS.

The situation of the fixed stars being always the same with respect to one another, they have their proper places assigned to them on the globe.

But to the planets no certain place can be assigned, their situation always varying.

* Fairman's Geography.

That space in the heavens, within the compass of which the planets appear, is called the zodiac. The latitude of the planets scarce ever exceeding 8 degrees, the zodiac is said to reach about 8 degrees on each side the ecliptic.

Upon the celestial globe, on each side of the ecliptic, are drawn eight parallel circles, at the distance of one degree from each other, including a space of 16 degrees; these are crossed at right angles, with segments of great circles at every 5th degree of the ecliptic; by these, the place of a planet on the globe, on any given day, may be ascertained with accuracy.

PROBLEM XXXVIII.

To find the place of any planet upon the globe, and by that means to find it's place in the heavens: also, to find at what hour any planet will rise or set, or be on the meridian, on any day in the year.

Rectify the globe to the latitude and sun's place, then place the planet's longitude and latitude in an ephemeris, and set the graduated edge of the moveable meridian to the given longitude in the ecliptic, and counting so many degrees amongst the parallels in the zodiac, either above or below the ecliptic, as her latitude is north or south; and set the center of the artificial sun to that point, and the centre will represent the place of the planet for that time.

Or fix the quadrant of altitude over the pole of the ecliptic, and holding the globe fast, bring the edge of the quadrant to cut the given degree of longitude on the ecliptic; then seek the given latitude on the quadrant, and the place under it is the point sought.

While the globe moves about it's axis, this point moving along with it will represent the planet's motion in the heavens. If the planet be brought to the eastern side of the horizon, the horary index will shew the time of it's rising. If the artificial sun is above the horizon, the planet will not be visible: when the planet is under the strong brazen meridian, the hour index shews the time it will be on that circle in the heavens: when it is at the western edge, the time of it's setting will be obtained.

PROBLEM XXXIX.

To find directly the planets which are above the horizon at sun-set, upon any given day and latitude.

Find the sun's place for the given day, bring it to the meridian, set the hour index to XII, and elevate the pole for the given latitude: then bring the place of the sun to the western semicircle of the horizon, and observe what signs are in that part of the ecliptic above the horizon, then cast your eye upon the ephemeris for that month, and you will at once see what planets possess any of those elevated signs; for such will be visible, and fit for observation on the night of that day.

PROBLEM XL.

To find the right ascension, declination, amplitude, azimuth, altitude, hour of the night, &c. of any given planet, for a day of a month and latitude given.

Rectify the globe for the given latitude and day of the month; then find the planet's place, as before directed, and then the right ascension, declination, amplitude, azimuth, altitude, hour, &c. are all found, as directed in the problems for the sun; there being no difference in the process, no repetition can be necessary.

OF THE USE OF THE CELESTIAL GLOBE, IN PROBLEMS RELATIVE TO THE MOON.

From the sun and planets we now proceed to those problems that concern the moon, the brilliant satellite of our earth, which every month enriches it with it's presence; by the mildness of it's light softening the darkness of night; by it's influence affecting the tide; and by the variety of it's aspects, offering to our view some very remarkable phenomena.

> " Soon as the ev'ning shades prevail,
> The moon takes up the wond'rous tale;
> And nightly to the list'ning earth,
> Repeats the story of her birth:
> Whilst all the stars that round her burn,
> And all the planets in their turn,
> Confirm the tidings as they roll,
> And spread the truth from pole to pole."

As the orbit of the moon is constantly varying in its position, and the place of the node always changing, as her motion is even variable in every part of her orbit, the solutions of the problems which relate to her, are not altogether so simple as those which concern the sun.

The moon increases her longitude in the ecliptic every day, about 13 degrees, 10 minutes, by which means she crosses the meridian of any place about 50 minutes later than she did the preceding day.

Thus if on any day at noon her place (longitude) be in the 12th degree of Taurus, it will be 13 deg. 10 min. more, or 25 deg. 10 min. in Taurus on the succeeding noon.

It is new moon when the sun and moon

have the same longitude, or are in or near the same point of the ecliptic.

When they have opposite longitudes, or are in opposite points of the ecliptic, it is full moon.

To ascertain the moon's place with accuracy, we must recur to an ephemeris; but as even in most ephemerides the moon's place is only shewn at the beginning of each day, or XII o'clock at noon, it becomes necessary to supply by a table this deficiency, and assign thereby her place for any intermediate time.

In the nautical ephemeris, published under the authority of the Board of Longitude, we have the moon's place for noon and midnight, with rules for accurately obtaining any intermediate time; but as this ephemeris may not always be at hand, we shall insert, from Mr. Martin's treatise on the globes, a table for finding the hourly motion of the moon. In order, however, to use this table, it will be necessary first *to find the quantity of the moon's diurnal motion in the ecliptic*, for any given day; for the quantity of the moon's diurnal motion varies from about 11 deg. 46 min. the least, to 15 deg. 16 min. when greatest.

The following tables are calculated from the least of 11 deg. 46 min. to the greatest of 15 deg. 16 min. every column increasing 10 minutes; upon the top of the column is the quantity of the diurnal motion, and on the side of the table are the 24 hours, by which means it will be easy to find what part of the diurnal motion of the moon answers to any given number of hours.

Thus suppose the diurnal motion to be 12° 32′, look on the top column for the number nearest to it, which you will find to be 12° 36′, in the sixth column; and under it, against 9 hours, you will find 4 deg. 43 min. which is her motion in the ecliptic in the space of 9 hours for that day. The quantity of the diurnal motion for any day is found by taking the difference between it and the preceding day.

Thus let the diurnal motion for the 11th of May, 1787, be required.

	SIGNS.	DEG.	MIN.
On the 11th of May her place was	11	2	35
On the 10th of May - -	10	19	47
The diurnal motion sought		12	48

TABLES

FOR FINDING THE HOURLY MOTION OF THE MOON, AND THEREBY HER TRUE PLACE AT ANY TIME OF THE DAY.

TABLE I.

HOURS.	11 46	11 56	12 6	12 16	12 26	12 36	12 46	12 56	13 6	13 16	13 26
	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.
1	0 29	0 30	0 30	0 30	0 31	0 31	0 32	0 32	0 33	0 33	0 34
2	0 59	1 0	1 0	1 1	1 2	1 33	1 4	1 5	1 5	1 6	1 43
3	1 28	1 20	1 31	1 32	1 33	1 35	1 36	1 37	1 38	1 39	1 41
4	1 58	1 59	2 1	2 3	2 4	2 6	2 8	2 9	2 11	2 13	2 14
5	2 27	2 29	3 31	2 34	2 35	2 37	2 40	2 42	2 44	2 46	2 48
6	2 57	2 59	3 1	3 4	3 6	3 9	3 11	3 14	3 16	3 19	3 21
7	3 26	3 29	3 32	3 35	3 38	3 40	3 43	3 46	3 49	3 52	3 55
8	3 55	3 59	4 2	4 6	4 9	4 12	4 15	4 19	4 22	4 25	4 20
9	4 25	4 28	4 32	4 36	4 40	4 43	4 47	4 51	4 55	4 58	5 2
10	4 54	4 58	5 3	5 7	5 11	5 1	5 19	5 23	5 27	5 32	5 56
11	5 24	5 28	5 33	5 37	5 42	5 4	5 51	5 56	6 0	6 3	6 9
12	5 53	5 53	6 3	6 8	6 13	6 18	6 23	6 28	6 33	6 38	6 43
13	6 22	6 28	6 33	6 39	6 44	6 49	6 55	7 0	7 6	7 11	7 17
14	6 52	6 58	7 3	7 9	7 15	7 21	7 27	7 33	7 38	7 44	7 50
15	7 21	7 27	7 34	7 40	7 46	7 52	7 59	8 5	8 11	8 17	8 24
16	7 51	7 57	8 4	8 11	8 17	8 24	8 31	8 37	8 44	8 51	8 57
17	8 20	8 27	8 34	8 41	8 48	8 55	9 3	9 10	9 17	9 24	9 31
18	8 49	8 57	9 4	9 12	9 19	9 27	9 34	9 42	9 49	9 57	10 4
19	9 19	9 26	9 35	9 43	9 51	9 58	10 6	10 14	10 22	10 30	10 38
20	9 48	9 56	10 5	10 13	10 21	10 30	10 38	10 47	10 55	11 3	11 12
21	10 17	10 26	10 36	10 44	10 53	11 1	11 10	11 19	11 27	11 36	11 43
22	10 47	10 56	11 6	11 15	11 21	11 33	11 42	11 51	12 0	12 10	12 19
23	11 17	11 26	11 36	11 46	11 55	12 4	12 14	12 24	12 33	12 43	12 52
24	11 46	11 56	12 6	12 16	12 26	12 36	12 46	12 56	13 6	13 16	13 26

TABLE II.

HOURS.	13 30	13 40	13 50	14 6	14 10	14 26	14 36	14 46	14 56	15 6	15 16
	d. m.	*d. m.*	*d. m.*	*d. m.*	*d. m.*	*d. m.*	*d. m.*	*d. m.*	*d. m.*	*d. m.*	*d. m.*
1	0 31	0 34	0 35	0 36	0 36	0 36	0 36	0 37	0 37	0 38	0 38
2	1 8	1 9	1 16	1 10	1 11	1 12	1 13	1 14	1 15	1 15	1 16
3	1 42	1 42	1 46	1 46	1 47	1 48	1 49	1 51	1 51	1 53	1 54
4	2 16	2 8	2 19	2 21	2 22	2 24	2 26	2 28	2 20	2 31	2 33
5	2 50	2 52	2 54	2 56	2 58	3 0	3 3	3 5	3 7	3 9	3 11
6	3 24	3 26	3 29	3 31	3 34	3 39	3 39	3 41	3 45	3 46	3 9
7	3 58	4 1	4 4	4 7	4 10	4 10	4 15	4 18	4 21	4 24	4 7
8	4 32	4 35	4 39	4 42	4 45	4 49	4 52	4 55	4 59	5 2	5 5
9	5 6	5 10	5 13	5 17	4 21	5 25	5 28	5 32	5 36	5 40	5 43
10	5 40	5 42	5 48	5 52	5 57	6 1	6 5	6 9	6 13	6 17	6 22
11	6 14	6 19	6 23	6 28	6 32	6 37	6 41	6 46	6 51	6 55	7 0
12	6 48	6 53	6 60	7 3	7 8	7 13	7 28	7 23	7 28	7 33	7 28
13	7 22	7 27	7 33	7 38	7 44	7 49	7 54	8 6	8 5	8 11	8 10
14	7 56	8 0	8 8	8 13	8 19	8 25	8 31	8 37	8 43	8 48	8 54
15	8 30	8 36	8 42	8 49	8 55	9 1	9 7	9 14	9 20	9 26	9 32
16	9 4	9 11	9 17	9 21	9 12	9 37	9 44	9 51	9 57	10 4	10 11
17	9 38	9 45	9 52	9 59	10 20	10 13	10 20	10 28	10 33	10 42	10 49
18	10 12	10 19	10 27	10 34	10 42	10 49	10 57	11 4	11 12	11 19	11 27
19	10 46	10 54	11 5	11 10	11 18	11 26	11 34	11 41	11 49	11 57	12 5
20	11 29	11 38	11 37	11 24	11 8	12 2	12 10	12 18	12 17	12 35	12 42
21	11 58	12 3	12 11	12 20	12 9	12 38	12 40	12 55	13 4	13 13	13 21
22	12 28	12 37	12 46	12 55	13 5	13 14	13 23	13 33	13 41	13 50	13 50
23	13 2	13 12	13 21	13 31	13 43	13 59	13 59	14 9	14 10	14 28	14 38
24	13 36	13 46	13 56	14 6	14 16	14 26	14 36	14 46	14 56	15 6	15 16

The moon's path may be represented on the globe in a very pleasing manner, by tying a silken line over the surface of the globe exactly on the ecliptic; then finding, by an ephemeris, the place of the nodes for the given time, confine the silk at these two points, and at 90 degrees distance from them elevate the line about 5¼ deg. from the ecliptic, and depress it as much on the other, and it will then represent the lunar orbit for that day.

PROBLEM XLI.

To find the moon's place in the ecliptic, for any given hour of the day.

First without an ephemeris, only knowing the age of the moon, which may be obtained from every common almanack.

Elevate the north pole of the celestial globe to 90 degrees, and then the equator will be in the plane of, and coincide with the broad paper circle; bring the first point of Aries, marked ♈ on the globe, to the day of the new moon on the said broad paper circle, which answers to the sun's place for that day; and the day of the moon's age will stand against the sign and degree of the moon's mean place; to which place apply a small patch to represent the moon.

But if you are provided with an ephemeris,* that will give the moon's latitude and place in the ecliptic; first note her place in the ecliptic upon the globe, and then counting so many degrees amongst the parallels in the zodiac, either above or below the ecliptic, as her latitude is north or south upon the given day, and that will be the point which represents the true place of the moon for that time, to which apply the artificial sun, or a small patch.

Thus on the 11th of May, 1787, she was at noon in 2 deg. 35 min. of Pisces, and her latitude was 4 deg. 18 min.; but as her diurnal motion for that day is 12 48 in nine hours, she will have passed over 4 deg. 47 min. which added to her place at noon, gives 7 h. 22 min. for her place on the 11th of May, at nine at night.

PROBLEM XLII.

To find the moon's declination for any given day or hour.

The place in her orbit being found, by prob. xli, bring it to the brazen meridian; then the arch of the meridian contained between it and the equinoctial, will be the declination sought.

* The nautical almanack is the best English ephemeris.

PROBLEM XLIII.

To find the moon's greatest and least meridian altitudes in any given latitude, that of London for example.

It is evident, this can happen only when the ascending node of the moon is in the vernal equinox; for then her greatest meridian altitude will be 5 deg. greater than that of the sun, and therefore about 67 deg.; also her least meridian altitude will be 5 deg. less than that of the sun, and therefore only 10 deg.: there will therefore be 57 deg. difference in the meridian altitude of the moon; whereas that of the sun is but 47 deg.

N. B. When the same ascending node is in the autumnal equinox, then will her meridian altitude differ by only 37 deg.; but this phenomenon can separately happen but once in the revolution of a node, or once in the space of nineteen years: and it will be a pleasant entertainment to place the silken line to cross the ecliptic in the equinoctial points alternately; for then the reason will more evidently appear, why you observe the moon sometimes within 23 deg. of our zenith, and at other times not more than 10 deg. above the horizon, when she is full south.

PROBLEM XLIV.

To illustrate, by the globe, the phenomenon of the harvest moon.

About the time of the autumnal equinox, when the moon is at or near the full, she is observed to rise almost at the same time for several nights together; and this phenomenon is called the *harvest moon.*

This circumstance, with which farmers were better acquainted than astronomers, till within these few years, they gratefully ascribed to the goodness of God, not doubting that he had ordered it on purpose to give them an immediate supply of moon-light after sun-set, for their greater convenience in reaping the fruits of the earth.

In this instance of the harvest moon, as in many others discoverable by astronomy, the wisdom and beneficence of the Deity is conspicuous, who really so ordered the course of the moon, as to bestow more or less light on all parts of the earth, as their several circumstances or seasons render it more or less serviceable.*

About the equator, where there is no variety of seasons, moon-light is not necessary for gathering in the produce of the ground; and

* Ferguson's Astronomy.

there the moon rises about 50 minutes later every day or night than on the former. At considerable distances from the equator, where the weather and seasons are more uncertain, the autumnal full moons rise at sun-set from the first to the third quarter. At the poles, where the sun is for half a year absent, the winter full moons shine constantly without setting, from the first to the third quarter.

But this observation is still further confirmed, when we consider that this appearance is only peculiar with respect to the full moon, from which only the farmer can derive any advantage; for in every other month, as well as the three autumnal ones, the moon, for several days together, will vary the time of it's rising very little; but then in the autumnal months this happens about the time when the moon is at the full; in the vernal months, about the time of new moon; in the winter months, about the time of the first quarter; and in the summer months, about the time of the last quarter.

These phenomena depend upon the different angles made by the horizon, and different parts of the moon's orbit, and that the moon can be full but once or twice in a year, in those parts of her orbit which rise with the least angles.

The moon's motion is so nearly in the

ecliptic, that we may consider her at present as moving in it.

The different parts of the ecliptic, on account of it's obliquity to the earth's axis, make very different angles with the horizon as they rise or set. Those parts, or signs, which rise with the smallest angles, set with the greatest, and *vice versa*. In equal times, whenever this angle is least, a greater portion of the ecliptic rises, than when the angle is larger.

This may be seen by elevating the globe to any considerable latitude, and then turning it round it's axis in the horizon.

When the moon, therefore, is in those signs which rise or set with the smallest angles, she will rise or set with the least difference of time; and with the greatest difference in those signs which rise or set with the greatest angles.

Thus in the latitude of London, at the time of the vernal equinox, when the sun is setting in the western part of the horizon, the ecliptic then makes an angle of 62 deg. with the horizon; but when the sun is in the autumnal equinox, and setting in the same western part of the horizon, the ecliptic makes an angle but of 15 deg. with the horizon; all which is evident by a bare inspection of the globe only.

Again, according to the greater or less inclination of the ecliptic to the horizon, so a greater or less degree of motion of the globe about it's axis will be necessary to cause the same arch of the ecliptic to pass through the horizon; and consequently the time of it's passage will be greater or less, in the same proportion; but this will be best illustrated by an example.

Therefore, suppose the sun in the vernal equinox, rectify the globe for the latitude of London, and the place of the sun; then bring the vernal equinox, or sun's place, to the western edge of the horizon, and the hour index will point precisely to VI; at which time, we will also suppose the moon to be in the autumnal equinox, and consequently at full, and rising exactly at the time of sun-set.

But on the following day, the sun, being advanced scarcely one degree in the ecliptic, will set again very nearly at the same time as before; but the moon will, at a mean rate, in the space of one day, pass over 13 deg. in her orbit; and therefore, when the sun sets in the evening after the equinox, the moon will be below the horizon, and the globe must be turned about till 13 deg. of Libra come up to the edge of the horizon, and then the index will point to 7 h. 16 min. the time of the moon's rising, which is an hour and quarter after sunset for dark night. The next day following there will be 2½ hours, and so on successively, with an increase of 1¼ hour dark night each evening respectively, at this season of the year; all owing to the very great angle which the ecliptic makes with the horizon at the time of the moon's rising.

On the other hand, suppose the sun in the autumnal equinox, or beginning of Libra, and the moon opposite to it in the vernal equinox, then the globe (rectified as before) being turned about till the sun's place comes to the western edge of the horizon, the index will point to VI, for the time of the setting, and the rising of the full moon on that equinoctial day. On the following day, the sun will set nearly at the same time; but the moon being advanced (in the 24 hours) 13 deg. in the ecliptic, the globe must be turned about till that arch of the ecliptic shall ascend the horizon, which motion of the globe will be very little, as the ecliptic now makes so small an angle with the horizon, as is evident by the index, which now points to VI h. 17. min. for the time of the moon's rising on the second day, which is about a quarter of an hour after sun-set. The third day, the moon will rise within half an hour; on the fourth, within three quarters of an hour, and so on; so that it will be near a week before the nights will be an hour without illumination; and in greater latitudes this difference will be still greater, as you will easily find by varying the case, in the practice of this celebrated problem, on the globe.

This phenomenon varies in different years; the moon's orbit being inclined to the ecliptic about five degrees, and the line of the nodes continually moving retrograde, the inclination of her orbit to the equator will be greater at some seasons than it is at others, which prevents her hastening to the northward, or descending southward, in each revolution, with an equal pace.

PROBLEM. XLV.

To find what azimuth the moon is upon at any place when it is flood, or high water; and thence the high tide for any day of the moon's age at the same place.

Having observed the hour and minute of high water, about the time of new or full moon, rectify the globe to the latitude and sun's place; find the moon's place and latitude in an ephemeris, to which set the artificial moon,* and screw the quadrant of altitude in the zenith; turn the globe till the horary index points to the time of flood, and lay the quadrant over the center of the artificial moon, and it will cut the horizon in the point of the compass upon

* Or patch representing the moon.

which the moon was, and the degrees on the horizon contained between the strong brass meridian and the quadrant, will be the moon's azimuth from the south.

To find the time of high water at the same place.

Rectify the globe to the latitude and zenith, find the moon's place by an ephemeris for the given day of her age, or day of the month, and set the artificial moon to that place in the zodiac; put the quadrant of altitude to the azimuth before found, and turn the globe till the artificial moon is under it's graduated edge, and the horary index will point to the time of the day on which it will be high water.

THE USE OF THE CELESTIAL GLOBE IN THE SOLUTION OF PROBLEMS ASCERTAINING THE PLACES AND VISIBLE MOTIONS OF ORBITS OR COMETS.*

There is another class or species of planets, which are called *comets*. These move round the sun in regular and stated periods of times, in the same manner, and from the same cause, as the rest of the planets do; that is, by a centripetal force, every where decreasing as the

* Martin's Description and Use of the Globes.

squares of the distances increase, which is the general law of the whole planetary system. But this centripetal force in the comets being compounded with the projectile force, in a very different ratio from that which is found in the planets, causes their orbits to be much more elliptical than those of the planets, which are almost circular.

But whatever may be the form of a comet's orbit in reality, their geocentric motions, or the apparent paths which they describe in the heavens among the fixed stars, will always be circular, and therefore may be shewn upon the surface of a celestial globe, as well as the motions and places of any of the rest of the planets.

To give an instance of the cometary praxis on the globe, we shall chuse that comet, for the subject of these problems, which made it's appearance at Boston, in New England, in the months of October and November, 1758, in it's return to the sun; after which, it approached so near the sun, as to set *heliacally*, or to be lost in it's beams for some time spent in passing the perihelion. Then afterwards emerging from the solar rays, it appeared retrograde in it's course from the sun towards the latter end of March, and so continued the whole month of April, and part of May, in the West Indies, particularly in Jamaica, whose latitude rendered it visible in those parts, when it was, for the greatest part of the time, invisible to us, by reason of it's southern course through the heavens.

When two observations can be made of a comet, it will be very easy to assign it's course, or mark it out upon the surface of the celestial globe. These, with regard to the above-mentioned comet, we have, and they are sufficient for our purpose in regard to the solution of cometary problems.

By an observation made at Jamaica on the 31st of March, 1759, at five o'clock in the morning, the comet's altitude was found to be 22 deg. 50 min. and it's azimuth 71 deg. south-east. From hence we shall find its place on the surface of the globe by the following problem.

PROBLEM XLVI.

To rectify the globe for the latitude of the place of observation in Jamaica, latitude 17 *deg.* 30 *min. and given day of the month, viz. March* 31*st.*

Elevate the north pole to 17 deg. 30 min. above the horizon, then fix the quadrant of altitude to the same degree in the meridian, or zenith point. Again, the sun's place for the 31st of March is in 10 deg. 34. min. ♈, which bring to the meridian, and set the hour index at XII, and the globe is then rectified for the place and time of observation.

PROBLEM XLVII.

To determine the place of a comet on the surface of the celestial globe from it's given altitude, azimuth, hour of the day, and latitude of the place.

The globe being rectified to the given latitude, and day of the month, turn it about towards the east, till the hour index points to the given time, viz. V o'clock in the morning; then bring the quadrant of altitude to intersect the horizon in 71 deg. the given azimuth in the south-east quarter; then, under 22 deg. 50 min. the given altitude, you will find the comet's place, where you may put a small patch to represent it.

PROBLEM XLVIII.

To find the latitude, longitude, declination, and right ascension of the comets.

In the circles of latitude contained in the zodiac, you will find the latitude of the comet to be about 30 deg. 30 min. from the ecliptic; the same circle of latitude reduces it's place to the ecliptic in 26 deg. 30 min. of ♒, which is it's longitude sought. Then bring the cometary parch to the brazen meridian, and it's declination will be shewn to be 9 deg. 15 min. south. At the same time, it's right aseension will be 227 deg. 30 min.

PROBLEM XLIX.

To shew the time of the comet's rising, southing, setting, and amplitude, for the day of the obserservation at Jamaica.

Bring the place of the comet into the eastern semicircle of the horizon, (the globe being rectified as directed) the index will point to III hours 15 min. which is the time of it's rising in the morning at Jamaica, the amplitude 10 deg. very nearly to the south. The patch being brought to the meridian, the index points to IX o'clock 10 min. for the time of culminating, or being south to them. Lastly, bring the patch to touch the western meridian, and the index will point to III in the afternoon, for the time of the comet's setting, with ten deg. of southern amplitude, of course.

PROBLEM L.

From the comet's place being given, to find the time of it's rising in the horizon of London, on the 31st day of March, 1759.

For this purpose, you need only rectify the globe for the given latitude of London, and bring the cometary patch to the eastern horizon, and the index points to III hours 45 min. for the time of it's rising at London, with about 14 deg. of south amplitude; then turn the patch to the western horizon, and the index points to II hours 25 minutes, the time of it's setting.

N. B. From hence it appears, the comet rose soon enough that morning to have been observed at London, had the heavens been clear, and the astronomers had been before-hand apprized of such a phenomenon.

PROBLEM LI.

To determine another place of the same comet, from an observation made at London on the 6th day of May, at ten in the evening.

On the 6th day of May, 1759, at ten at night, the place of the comet was observed, and it's distance measured with a micrometer, from two fixed stars marked μ and ν in the constellation called *Hydra*, and it's altitude was found to be 16 deg. and it's azimuth 37 deg. south-west; from whence it's place on the surface of the globe, is exactly determined, as in prob. xlvii. and having stuck a patch thereon, you will have the two places of the comet on the surface of the globe, for the two distant days and places of observation, as required.

PROBLEM LII.

From two given places of a comet, to assign it's apparent path among the fixed stars in the heavens.

The two places of the comet being determined by the observations on the 31st of March, 1758, and the 6th of May following, and denoted by two patches respectively, you mnst move the globe up and down, in the notches of the horizon, till such time as you bring both the patches to coincide with the horizon; then will the arch of the horizon between the two patches shew, upon the celestial globe, the apparent place of the comet in the interval between the two observations, and by drawing a line with a black lead pencil along by the frame of the horizon, it's path on the surface of the globe will be delineated, as required. And here it may be observed, that it's apparent path lay through the following southern constellations, viz. the tail of Capricorn, the tail of Piscis Australis, by the head of Indus, the neck and body of Pavo, through the neck of Apus, below Triangulum Australe, above Musca, by the lowermost of the Crosiers, across the hind legs and through the tail of Centaurus, from thence between the two stars in the back of the Hydra before-mentioned; after this, it passed on to Sextans Uraniæ, and then to the ecliptic near Cor Leonis, soon after which it totally disappeared.

PROBLEM LIII.

To estimate the apparent velocity of a comet, two places thereof being given by observation.

Let one place be ascertained near the beginning of it's appearance, and the other towards the end thereof; then bring these two places to the horizon, and count the number of degrees intersected between them, which being the space apparently described in a given time, will be the velocity required. Thus, in the case of the above-mentioned comet, you will find that it described more than 150 deg. in the space of 36 days, which is more than 4 deg. per day.

PROBLEM LIV.

To represent the general phenomena of the comet, for any given latitude.

Bring the visible path of the comet to coincide with the horizon, by which it was drawn, and then observe what degree of the meridian is in the north point of the horizon, which, in the case of the foregoing comet, will be the 23 deg. This will shew the greatest latitude in which the whole path can be visible in any latitude less than this, as that of Jamaica; where, for instance, the most southern part of the path will be elevated more than 5 deg. above the horizon, and the comet visible through the whole time of it's apparition. But rectifying the globe for the latitude of London, the path of the said comet will be for the most part invisible, or below the horizon; and therefore it could not have been seen in our latitude, but at times very near the beginning and end of it's appearance; because, by bringing the comet's path on one part to the south point of the horizon, it will immediately appear in what part the comet ceases to be visible; and then the bringing the other part of the path to the point, it will appear in what part it will again become visible.

After this manner may the problems relating to any other comets be performed; and thus the paths of the several comets, which have hitherto been observed, may be severally delineated on the celestial globe, and their various phenomena in different latitudes be thereby shewn.

ESSAY III.

CONTAINING

A DESCRIPTION

OF THE MOST IMPROVED

PLANETARIUM, LUNARIUM, & TELLURIAN.

I Now proceed, in purſuance of my original plan, to deſcribe one of the inſtruments contrived to facilitate the ſtudy of geography and aſtronomy. It will realize to the eye of the pupil many phenomena, and impreſs them ſtrongly on his memory. The inſtrument here deſcribed may be conſidered as one of the beſt hitherto contrived for explaining the celeſtial motions. The deſcription of this will, with very few alterations, apply to moſt other inſtruments deſigned for the ſame purpoſe. The explanation of the inſtrument will alſo enable me to render ſome articles plainer, and to treat others more fully; while thoſe who have not thoroughly comprehended what has been already ſaid, may gain more perfect ideas of the ſubject.

It ſeems highly probable, that the ancients were not unacquainted with planetary machines, and that the ſame powers of genius which led them to contemplate and reaſon upon the motion of the heavenly bodies, induced them to realize their ideas, and form inſtruments for explaining them; and we may fairly preſume, that theſe were carried to no ſmall degree of perfection, when we conſider that of one, Archimedes was the maker, and Cicero the encomiaſt.

The inſtrument now to be deſcribed was invented by the celebrated *Huygens*, though ſince his time it has been aſcribed to almoſt as many inventors as makers; each deviation in form, the mounting it in this mode or the other, the addition of a zodiac, or ſome ſuch ſlight changes, have been deemed by many of ſufficient importance to give them a claim to the title of inventors:—be it ſo. Let the friend of ſcience encourage every humble effort to improve it; and let him beſtow a name which, though it may in ſome meaſure gratify vanity, yet incites to labour, rather than by contempt check the ardour, or diſcourage the talents which, when called forth, may be of the greateſt ſervice to ſociety.

Description of the Planetarium.

Fig. 1, plate XI, reprefents the planetarium. The box contains the wheel-work by which the planets are made to move round a brafs ball, reprefenting the fun: this motion is communicated to them by turning a handle.

A planetarium may be confidered, in fome fort, as a diametrical fection of our univerfe, in which the upper and lower hemifpheres are fuppreffed. The upper plate is to anfwer for the *ecliptic;* on this therefore are placed, in two oppofite circles, correfponding to each other, the figns of the ecliptic, and the days of the month, by means whereof the planets may be eafily fet to their mean places in the ecliptic for any day in the year. Through the center of the plate there paffes a ftrong ftem, on which the brafs ball ⊙ is placed, which reprefents the fun; round the ftem are the different fockets, which carry the arms, by which the balls reprefenting the planets are fupported. The planets are ivory balls, having the hemifphere which is next the fun white, the other black, to exhibit their refpective phafes to each other. The planets may be eafily put on or taken off their fockets, as occafion requires. About the primary planets are placed the fecondary planets, or moons, which are in this inſtrument only moveable by hand; but when the inſtrument is fitted upon a large ſcale, and in a more expenſive form, even theſe are put in motion by the wheel-work.

The planets are diſpoſed in the following order: in the center is the braſs ball ☉ to repreſent the ſun, then Mercury ☿, Venus ♀, the Earth ⊕, Mars ♂, Jupiter ♃, and Saturn ♄; then the Georgium Sidus ♅.

When the pupil has been gratified by putting the inſtrument in motion, and making his own obſervations on thoſe motions, it will be proper to acquaint him with the names of the different planets, and of their diviſion into primary and ſecondary, to ſhew him how they were firſt diſtinguiſhed from the fixed ſtars, and how the length of their periodic revolution was diſcovered. Here it will be proper to obſerve, that the annual motion of the earth, or the time it takes to perform it's period round the ſun, is made the baſis to which the others are compared; and this is one of the reaſons why the months, and days of our months, are engraved on the circle. Having obſerved this, the planets may be put in motion, and they will be found to revolve round the repreſentative of the ſun in their proportionable times, each planet always completing it's revolution in the fame fpace of time, in periods regulated and proportioned to their diftance from the fun: the curve which they defcribe in their revolution, is what is termed their orbit.

General Explanation of the Solar System by the Planetarium.

In the center of the fyftem is the fun, placed in the heavens by that *Almighty Power* who faid "Let there be light, and there was light," to be the fountain of light and heat to all the planets revolving round him.

————————" His rapid rays,
" Themfelves unmeafur'd, meafure all our days:
" A thoufand worlds confefs his quick'ning heat,
" And all he cheers are fruitful, fair, and fweet."

The fituation of this glorious body, in the fyftem, is pointed out in this machine by the brafs ball in the center.

Mercury is the neareft planet to the fun and moves round him in about 88 days. To obferve this by the planetarium, obferve the parts of the ecliptic where Mercury and Venus are fituated, or fet them to any two given places therein, and then turn the handle; and when Mercury is returned to the place from whence he fet out, the earth will have gone over 88 days of the ecliptic. In the fame manner you will find the periods of the other planets correfponding to their refpective periods in the heavens.

As Mercury moves round him in rather lefs than three months, that confequently is the length of his year ; the year in each planet being the fpace of time which it occupies in going round the fun. Mercury is feldom feen, on account of his being fo near to the fun as to be generally concealed by his rays ; and the time of his rotation on his axis, or the length of his days and nights, has not yet been difcovered.

Venus, the next planet to Mercury, diftinguifhed in the heavens by her fuperior luftre and brightnefs, completes her annual or yearly revolution round the fun in about 225 days ; and her diurnal or daily rotation upon her own axis in about 23½ hours. When this planet appears to the weft of the fun, fhe rifes before him in the morning, and is called the morning ftar ; and when fhe appears to the eaft of the fun, fhe fhines in the evening after he fets, and is then called the evening ftar ; being in each fituation, alternately, for about 7½ months.

The next planet above Venus is *the Earth*, whofe annual revolution is performed in 365 days, 5 hours, and 49 minutes, or rather more than 12 months, (the brazen ecliptic is however only divided into 365 days) and it's diurnal rotation in about 24 hours. Every fourth year, one day is added at the end of February, to recover the time which the earth ſpends in her annual courſe above the 365 days, which compoſe a common year. This fourth year therefore conſiſts of 366 days, and is called biſſextile, and alſo leap-year.

Next above the earth's orbit is that of *Mars*, who completes his revolution round the ſun in ſomewhat leſs than two of our years, and his rotation upon his axis in rather more than 24½ hours.

Jupiter, the largeſt of all the planets, holds the next place to Mars in diſtance from the ſun. He performs his annual revolution in rather leſs than 12 years, and his diurnal rotation in about 10 hours. Jupiter, as well as Venus, is ſometimes called a morning, and ſometimes an evening ſtar.

Next to the orbit of Jupiter is that of *Saturn*, who completes his annual revolution round the ſun in about 29½ years. The time of his diurnal rotation is unknown.

Saturn was generally conſidered as the remoteſt planet of our ſyſtem, till, on the 13th of March, 1781, Dr. Herſchel diſcovered another, ſtill further diſtant from the ſun, round which it revolves, in an orbit nearly circular, in about 82 years. To this planet Dr. Herſchel has given the name of the Georgium Sidus.

Befides thefe feven *primary* planets, there are fourteen others, called *fecondary* planets, or *fatellites*, which move round their primaries in the fame manner as thefe move round the fun.

The firft of thefe is the *moon*, reprefented by the fmall ball annexed to the earth. While it accompanies the earth in it's annual progrefs through it's orbit, it is continually revolving round it; as you will fee in that part of the inftrument that is particularly defigned to illuftrate the phenomena of the moon.

Jupiter has four fatellites, Saturn feveral, and the Georgium Sidus two; they are all invifible to the naked eye, and are only to be feen by the affiftance of telefcopes. Saturn, befides his feven fatellites, has a bright fhining ring, which encompaffes him: it is at fuch a diftance from his body, that the fixed ftars may frequently be feen between the inner edge of the ring and the planet itfelf. Dr. Herfchel has lately difcovered that this ring is divided into two parts, an inner and an outer ring, which are feparated from each other by a fpace of one thoufand miles.

To explain, by the planetarium, why the ſun, being a fixed body, appears to paſs through all the ſigns of the zodiac in twelve months, or one year. It will ſhew that this phenomenon is occaſioned by the annual motion of the earth.

As the general phenomena of the planetary ſyſtem will be beſt underſtood by an induction of particulars, I ſhould adviſe the tutor to remove all the planets but thoſe whoſe motion he is going to explain; for inſtance, let him now leave only the earth and ſun; place the earth over *Libra*, and it is plain that the ſun will then be transferred by the eye of the ſpectator to *Aries*, in which ſign it will appear at the latter end of March: move the earth on in it's orbit to Capricornus, and the ſun will appear at Cancer in June, ſeeming to have moved from ♈ to ♋, though it has not ſtirred, the real motion of the earth having cauſed the ſpectator to transfer the ſun to all the intermediate points in the heavens, and thus given it an apparent motion. Continue to move the earth till it arrives at Aries, and the ſun will be ſeen in Libra in the month of September: moving the earth on to Cancer, the viſual ray of the ſpectator refers the ſun to Capricorn, as it appears in the month of December. Laſtly, continue moving the earth, and it will arrive at

Aries, where we ſet out. Thus we have ſhewn that it is the motion of the earth which cauſes the ſun to appear in all the different ſigns of the zodiac. Cuſtom, indeed, has taught us to ſay *the ſun is in Aries*, when it is between us and Aries, and ſo of any other ſign; whereas it would have been more proper to ſay, that the earth is in Libra.

To ſhew why at different times of the year we ſee the heavens decorated with an entire different collection of ſtars.

This phenomenon is occaſioned by the earth's progreſſive or annual motion; while the earth is traverſing his courſe under the vaſt concave of fixed ſtars, we are gradually carried under the different conſtellations. From hence it is evident, that at night when the earth is turned from the ſun, we ſhall in ſucceſſion have the opportunity of viewing from time to time all the ſtars in the zodiac, and conſequently a different conſtellation will preſent itſelf every month.

Thus, the Pleiades are not viſible in the ſummer; but in the winter the earth is got between the ſun and them. Theſe ſtars are obſervable at night, becauſe they are not intercepted from our ſight by the ſun's rays; and in this manner they appear during the whole winter, only they feem to get more wefterly every night, as the earth moves gradually by them to the eaft. To make this ftill more clear, place the earth in the planetarium between the fun and any of the figns, that fide towards the fun will be day, and that towards the fign night: it follows, that at night we are turned towards the ftars, which in that fign (fuppofe, as before, the Pleiades in Taurus) will then be confpicuous to us; but as the fpring approaches, the earth withdraws itfelf from between the fun and the Pleiades, till at length the earth, by it's progreffive motion, gets the fun between it and the ftars, which then lie hid behind the folar rays: after the fame manner, while the earth performs her annual tract, the fun, which always feems to move the contrary way, darkens, by his fplendor, the other conftellations fucceffively; but the ftars oppofite to thofe hid by the fun, are at night prefented to our view.

General Phenomena of the Planets.

Let the tutor now place the earth, Mars, and Venus, on the planetarium; and as each planet moves with a different degree of velocity, they are continually changing their relative pofitions. Thus on turning the handle of the machine, he will find, 1ft, that the earth moves twice as faft as Mars, making two revolutions while he makes one; and Venus, on the other hand, moves much faſter than the earth. Secondly, that in each revolution of the earth theſe planets continually change their relative poſitions, correſponding ſometimes with the ſame point of the ecliptic, but much oftener with different points.

To explain the conjunction, oppoſition, elongation, and other phenomena of the inferior planets.

I may now proceed to make ſome obſervations on the motions of Venus, as obſerved in the planetarium. If conſidered as viewed from the ſun, we ſhall find that Venus would appear at one time nearer to the earth than at another; that ſometimes ſhe would appear in the ſame part of the heavens, and at others in oppoſite parts thereof.

As the planets, when ſeen from the ſun, change their poſition with reſpect to the earth, ſo do they alſo, when ſeen from the earth, change their poſition with reſpect to the ſun, being ſometimes nearer to, at others farther from, and at times in conjunction with him.

But the conjunctions of Venus or Mercury, ſeen from the earth, not only happen when they are ſeen together from the ſun, but alſo when they appear to be in oppoſition to the ſolar ſpectator. To illuſtrate this, bring the earth and Venus to the firſt point of Capricorn; then by applying a ſtring from the ſun over Venus and the earth, you will find them to be in conjunction, or on the ſame point of the ecliptic.

Whereas if you turn the handle till the ſun is between Venus and the earth, a ſpectator in the ſun will ſee Venus and the earth in oppoſition; but an inhabitant of the earth will ſee Venus not in oppoſition to the ſun, but in conjunction with him.

In the firſt conjunction Venus is between the ſun and earth; this is called the inferior conjunction. In the ſecond, the ſun is ſituated between the earth and Venus; this is called the ſuperior conjunction.

After either of theſe conjunctions, Venus will be ſeen to recede daily from the ſun, but never departing beyond certain bounds, never appearing oppoſite to the ſun; but when ſhe is ſeen at the greateſt diſtance from him, a line joining her centre with the centre of the earth, will be a tangent to the orbit of Venus.

To illuſtrate this, take off the ſun from it's ſupport, and the ball of Venus from it's ſupporting ſtem; place the wire, fig. 2, plate XI, ſo that the part P may be on the ſtem that ſupports the earth, and a ſimilar ſocket, fig. 3, on the pin which ſupports the ball of Venus; the wire F is to lie in a notch at the top of the ſocket, which has been put upon the ſupporting ſtem of Venus; then will the wire repreſent a viſual ray going from an inhabitant of the earth to Venus. By turning the handle, you will now find that the planet never departs further than certain limits from the ſun, which are called it's greateſt elongations, when the wire becomes a tangent to the orbit; after which, it approaches the ſun, till it arrives at either the inferior or ſuperior conjunction.

It will alſo be evident from the inſtrument, that Venus, from her ſuperior conjunction, when ſhe is furtheſt from the earth, to the time of her inferior conjunction, when ſhe is neareſt, ſets later than the ſun, is ſeen after ſun-ſet, and is, as it were, the forerunner of night and darkneſs. But from the inferior conjunction, till ſhe comes to the ſuperior one, ſhe is always ſeen weſtward of the ſun, and muſt conſequently ſet before him in the evening, and riſe before him in the morning, foretelling that light and day are at hand.

Bring Venus and the earth to the beginning of Aries, when they will be in conjunction; and turn the handle for nearly 225 days, and as Venus moves faſter than the earth, ſhe will be come to Aries, and have finiſhed her courſe, but will not have overtaken the earth, who has moved on in the mean time; and Venus muſt go on for ſome time, in order to overtake her. Therefore, if Venus ſhould be this day in conjunction with the ſun, in the inferior part of her orbit, ſhe will not come again to the ſame conjunction till after 1 year, 7 months, and 12 days.

It is alſo plain, by inſpection of the planetarium, that though Venus does always keep nearly at the ſame diſtance from the ſun, yet ſhe is continually changing her diſtance from the earth; her diſtance is greateſt when ſhe is in her ſuperior, and leaſt when ſhe is in her inferior conjunction.

To explain the phaſes, the retrograde, direct, and ſtationary ſituations of the planets.

As Venus is an opake globe, and only ſhines by the light ſhe receives from the ſun, that face which is turned towards the ſun will always be bright, while the oppoſite one will be in darkneſs; conſequently, if the ſituation of the earth be ſuch, that the dark ſide of Venus be turned towards us, ſhe will then be inviſible, except ſhe appear like a ſpot on the diſk of the ſun. If her whole illuminated face is turned towards the earth, as it is in her ſuperior conjunction, ſhe appears of a circular form; and according to the different poſitions of the earth and Venus, ſhe will have different forms, and appear with different phaſes, undergoing the ſame changes of form as the moon. Theſe different phaſes are ſeen very plain in this inſtrument, as the ſide of the planet, which is oppoſite to the ſun, is blackened; ſo that in any poſition, a line drawn from the earth to the planet, will repreſent that part of her diſk which is viſible to us.

The irregularities in the apparent motions of the planets, is a ſubject that this inſtrument will fully elucidate; and the pupil will find that they are only apparent, taking their riſe from the ſituation and motion of the obſerver. To illuſtrate this, let us ſuppoſe the above-mentioned wire, when connected with Venus and the earth, to be the viſual ray of an obſerver on the earth, it will then point out how the motions of Venus appear in the heavens, and the path ſhe appears to us to deſcribe among the fixed ſtars.

Let Venus be placed near her ſuperior conjunction, and the inſtrument in motion, the wire will mark out the apparent motion of Venus in the ecliptic. Thus Venus will appear to move eaſtward in the ecliptic, till the wire becomes a tangent to the orbit of of Venus, in which ſituation ſhe will appear to us to be ſtationary, or not to advance at all among the fixed ſtars; a circumſtance which is exceeding viſible and clear upon the planetarium.

Continue turning, till Venus be in her ſuperior conjunction, and you will find by the wire, or viſual ray, that ſhe now appears to move backward in the ecliptic, or from eaſt to weſt, till ſhe is arrived to that part where the viſual ray again becomes a tangent to her orbit. In which poſition, Venus will again appear ſtationary for ſome time; after which ſhe will commence anew her direct motion.

Hence, when Venus is in the ſuperior part of her orbit, ſhe is always ſeen to move directly, according to the order of the ſigns; but when ſhe is in the inferior part, ſhe appears to move in a contrary direction.

What has been ſaid concerning the motions of Venus, is applicable to thoſe of Mercury; but the conjunctions of Mercury with the ſun, as well as the times of his being direct, ſtationary, or retrograde, are more frequent than thoſe of Venus.

Of the ſuperior planets, as ſeen from the earth.

If the tutor wiſhes to extend his obſervations on the inſtrument to Mars, he will find by the viſual ray, that Mars, when in conjunction, and when in oppoſition, will appear in the ſame point of the ecliptic, whether it is ſeen from the ſun or the earth; and in this ſituation only is it's real and apparent place the ſame, becauſe then only the ray proceeds as if it came from the center of the univerſe.

He will obſerve, that the direct motion of the ſuperior planets is ſwifter the nearer it is to the conjunction, and ſlower when it is nearer to quadrature with the ſun; but that the retrograde motion of a ſuperior planet is ſwifter the nearer it is to oppofition, and flower the nearer it is to quadrature; but at the time of change from direct to retrograde, it's motion becomes infenfible.

To prove by the planetarium the truth of the Copernican, and abfurdity of the Ptolemaic fyftem.

Of all the prejudices which philofophy contradicts, there is none fo general as that the earth keeps it's place unmoved. This opinion feems to be univerfal, till it is corrected by inftruction, or by philofophical fpeculation. Thofe who have any tincture of education, are not now in danger of being held by it; but yet they find at firft a reluctance to believe that there are antipodes, that the earth is fpherical, and turns round it's axis every day, and round the fun every year. They can recollect the time when reafon ftruggled with prejudice upon thefe points, and prevailed at length, but not without fome efforts.*

The planetarium gives occular demonftration of the motion of the earth about the fun, by fhewing that it is thus only that the celeftial phenomena can be explained, and making the abfurdity of the Ptolemaic fyftem evident to the fenfes of young people. For this purpofe,

* Reid's Effays on the Intellectual Powers of Man.

take off the braſs ball which repreſents the ſun, and put on the ſmall ivory ball, which accompanies the inſtrument in it's place, to repreſent the earth, and place a ſmall braſs ball for the ſun, on that arm which carries the earth.

The inſtrument in this ſtate will give an idea of the Ptolemiac ſyſtem, with the earth immoveable in the center, and the heavenly bodies revolving about in the following order: Mercury, Venus, *the ſun*, Mars, Jupiter, and Saturn. Now, in this diſpoſition of the planets, ſeveral circumſtances are to be obſerved, that are contrary to the real appearances of the celeſtial motions, and which therefore prove the falſity of this ſyſtem.

It will appear from the inſtrument, that on this hypotheſis Mercury and Venus could never be ſeen to go behind the ſun, from the earth, becauſe the orbits of both of them are contained between the ſun and the earth; but theſe planets are ſeen to go as often behind the ſun as before it; we may, therefore, from hence conclude, that this ſyſtem is erroneous.

It is alſo apparent in the planetarium, that on this ſcheme theſe planets might be ſeen in conjunction with, or in oppoſition to the ſun, or at any diſtance from it. But this is contrary to experience, for they are never ſeen in oppoſition to the ſun, or on the meridian of

London, for inſtance, at midnight, nor ever recede fom it beyond certain limits.

Again, on the Ptolemiac ſyſtem all the planets would be at an equal diſtance from the earth, in all parts of their orbits, and would therefore neceſſarily appear always of the ſame magnitude, and moving with equal and uniform velocities in one direction; circumſtances which are known to be repugnant to obſervation and experience.

To rectify the planetarium, or place the planets in their true ſituations, as ſeen from the ſun.

The ſituations of the planets in the heavens are accurately calculated by aſtronomers, and publiſhed in almanacks appropriated to the purpoſe, as the Nautical Almanack, White's Ephemeris, &c. An ephemeris is a diary or daily regiſter of the motions and places of the heavenly bodies, ſhewing the ſituation of each planet at 12 o'clock each day. Theſe ſituations it exhibits both as ſeen from the ſun, and from the earth; but as the former, or the heliocentric, is the only one of any uſe for this purpoſe, we ſhall here inſert, and explain, ſo much of that part of Mr. White's ephemeris, as will enable the pupil to rectify his planetarium.

Days.	Day increas	Length of day.	Helioc. long. ♄	Helioc. long. ♃	Helioc. long. ♂	Helioc. long. ⊕	Helioc long. ♀	Helioc. long. ☿
1	7 4	14 48	27 ♓ 35	2 ♍ 14	27 ♌ 16	11 ♏ 14	8 ♐ 35	1 ♋ 18
7	7 24	15 8	27 47	2 42	29 57	17 2	18 7	26 ♊ 53
13	7 44	15 28	27 59	3 0	2 ♎ 39	21 52	7 37	3 ♌ 4
19	8 0	15 44	28 11	3 3,	5 20	28 36	7 ♑ 7	4 ♍ 15
25	8 10	16 0	28 23	4 5	8 3	4 ♐ 22	16 36	0 ♎ 0

In the foregoing table, for May, 1790, you have the heliocentric places calculated to every ſix days of the month, which is ſufficiently accurate for general purpoſes. Thus, on the 19th, you have Saturn in 28° 11′ of Piſces, Jupiter 3° 37′ of Virgo, Mars in 5° 20′ of Libra, the Earth 28° 36′ of Virgo. Venus 7° 7′ of Capricorn, and Mercury 4° 15′ of Virgo; to which places, on the ecliptic of the planetarium, the ſeveral planets are to be ſet, and they will then exhibit their real ſituations, both with reſpect to the ſun and the earth, for that day.

To uſe the inſtrument as a tellurian, plate XII, *fig.* 1.

The ſun, the earth, and the moon, are bodies which, from our connection with them, are ſo intereſting to us, that it is neceſſary to enter into a minute detail of their reſpective phenomena. To render this inſtrument a tellurian, all the planets are firſt to be taken off, the piece of wheel-work A B is to be placed on in their ſtead, in ſuch a manner, that the wheel c may fall into the teeth that are cut upon the edge of the ecliptic. The milled nut D is then to be fcrewed on, to keep the wheel-work firmly in it's place. It is beft to place this wheel-work in fuch a manner, that the index E may point to the 21ft of June, and then to move the globe, fo that the north pole may be turned towards the fun.

The inftrument will then fhew, in an accurate and clear manner, all the phenomena arifing from the annual and diurnal motion of the earth; as the globe is of three inches diameter, all the continents, feas, kingdoms, &c. may be diftinctly feen; the equator, the ecliptic, tropics, and other circles, are very vifible, fo that the problems relative to peculiar places may be fatisfactorily folved. The axis of the earth is inclined to the ecliptic in an angle of 66½ degrees, and preferves it's parallelifm during the whole of it's revolution. About the globe there is a circle, to reprefent the *terminator*, or boundary between light and darknefs, dividing the enlightened from the dark hemifphere. At N O is an hour circle, to determine the time of fun-rifing or fetting.

The brafs index G reprefents a central folar ray; it ferves to fhew when it is noon, or when the fun is upon the meridian at any given place; it alfo fhews what fign and degree of the ecliptic on the globe the fun defcribes on any day, and the parallel it defcribes.

The plane of the terminator H I paſſes through the center of the earth, and is perpendicular to the central ſolar ray. The index E points out the ſun's place in the ecliptic of the inſtrument for any given day in the year.

To explain the changes of ſeaſons by the tellurian.

Before I ſhew how the ſeaſons are explained by the inſtrument, it is neceſſary to aſſume two propoſitions: 1. That a globular luminous body, ſending out parallel rays of light, will only enlighten one half of another globe, and that of courſe will be the hemiſphere turned towards the luminous body. 2. That the earth moves round the *ſun* in ſuch a manner, that in all parts of it's orbit it's axis is parallel to itſelf, and has a certain inclination to the plane of the orbit. Theſe being underſtood, the firſt thing to be done is to rectify the tellurian; or, in other words, to put the globe into a poſition ſimilar to that of the earth, for any given day. Thus to rectify the tellurian for the 21ſt of June, turn the handle till the annual index comes to the given day; then move the globe by the arm K L, ſo that the north pole may be turned towards the ſun; and adjuſt the terminator, ſo that it may juſt touch the edge of the arctic circle. The globe is then in the ſituation of the earth for the longeſt day in our northern hemiſphere, the annual index pointing to the firſt point of Cancer and the 21ſt of June; bring the meridian of London to coincide with the central ſolar ray, and move the hour circle N O, till the index L points to XII; we then have the ſituation of London with reſpect to the longeſt day.

Now, on gently turning the handle of the machine, the point repreſenting London will, by the rotation of the earth, be carried away towards the eaſt, while the ſun ſeems to move weſtward; and when London has arrived at the eaſtern part of the terminator, the index will point on the hour circle the time of ſun-ſetting for that day; continue to turn on, and London will move in the ſhaded part of the earth, on the other ſide of the terminator, when the index is again at XII, it is midnight at London; by moving on, London will emerge from the weſtern ſide of the terminator, and the index will point out the time of ſun-riſing, the ſun at that inſtant appearing to riſe above the horizon in the eaſt, to an inhabitant of London.

It will be evident by the inſtrument, while in this poſition, that the central ſolar ray, during the whole revolution of the earth on it's axis, only points to the tropic of Cancer, and that the ſun is vertical to no other part of the earth, but thoſe who are under this tropic.

By obſerving how the terminator cuts the ſeveral parallels of the globe, we ſhall find that all thoſe between the northern and ſouthern polar circles (except the equator) are divided unequally into diurnal and nocturnal arches, the former being greateſt on the north ſide of the equator, and the latter on the ſouth ſide of it.

In this poſition the northern polar circle is wholly on that ſide of the terminator which is neareſt the ſun, and therefore altogether in the enlightened hemiſphere, and the inhabitants thereof enjoy a continual day. In the ſame manner, the inhabitants of the ſouthern polar circle continue in the dark at this time, notwithſtanding the diurnal revolution of the earth; it is the annual motion only which can relieve them from this ſituation of perpetual darkneſs, and bring to them the bleſſings of day, and the enjoyments of ſummer; while in this ſtate the inhabitants in north latitude are neareſt to the central ſolar ray, and conſequently to the ſun's perpendicular beams, and of courſe a greater number of his rays will fall upon any given place, than at any other time; the ſun's rays do now alſo paſs through a leſs quantity of the atmoſphere, which, together, with the length of the day, and the ſhortneſs of the night, are the reaſons of the increaſe of heat in ſummer, together with all it's other delightful effects.

While the earth continues to turn round on it's own axis once a day, it is continually advancing from weſt to eaſt, according to the order of the ſigns, as is ſeen by the progreſs of the annual index E, which points ſucceſſively to all the ſigns and degrees of the ecliptic ; the ſun in the mean time ſeems to deſcribe the ecliptic alſo, going from weſt to eaſt, at the diſtance of ſix ſigns from the earth ; that is, when the earth really ſets out from the firſt point of Capricorn, the ſun ſeems to ſet out from the firſt point of Cancer, as is plain from the index.

But as during the annual revolution of the earth, the axis always remains parallel to itſelf, the ſituation of this axis, with reſpect to the ſun, muſt be continually changing.

As the earth moves on in the ecliptic, the northern polar circle gets gradually under the terminator, ſo that when the earth is arrived at the firſt point of Aries, and the annual index is at the firſt point of Libra on the 22d of September, this circle is divided into two equal parts by the terminator, as is alſo every other parallel circle, and conſequently the diurnal and nocturnal arches are equal ; this is called the time of equinox, the days and nights are then equal all over the earth, being each of them 12 hours long, as will be ſeen by the horary index L. The central ſolar ray G having ſucceſſively pointed to all the parallels that may be ſuppoſed to be between the equator and the tropic of Cancer, is at this period perpendicular to the inhabitants that live at the equator.

By continuing to turn the handle, the earth advances in the ecliptic, and the terminator ſhews how the days are continually decreaſing, and the diurnal arches ſhortening, till by degrees the whole ſpace contained by the northern polar circle is on that ſide of the terminator which is oppoſite to the ſun, which happens when the earth is got to the firſt point of Cancer, and the annual index is at the firſt point of Capricorn, on the 21ſt of December. In this ſtate of the globe, the northern polar circle, and all the country within that ſpace, have no day at all; whilſt the inhabitants that live within the ſouthern polar circle, being on that ſide of the terminator which is next the ſun, enjoy perpetual day. By this and the former ſituation of the earth, the pupil will obſerve that there are nations to whom a great portion of the year is darkneſs, who are condemned to paſs weeks and months without the benign influence of the ſolar rays. The central ſolar ray is now perpendicular to the tropic of Capricorn; the length of the days is inverſely what it was when the ſun entered Cancer, the days being now at their ſhorteſt, and the nights longeſt in the northern hemiſphere; the length of each is pointed out by the horary index.

The earth being again carried on till it enters Libra, and the ſun Aries, we ſhall again have all the phenomena of the equinoctial ſeaſons. The terminator will divide all the parallels into two equal parts; the poles will again be in the plane of the terminator, and conſequently, as the globe revolves, every place from pole to pole will deſcribe an equal arch in the enlightened and obſcure hemiſpheres, entering into and going out of each exactly at ſix o'clock, as ſhewn by the hour index.

As the earth advances, more of the northern polar circle comes into the illuminated hemiſphere and conſequently the days increaſe with us, while thoſe on the other ſide of the equator decreaſe, till the earth arrives at the firſt point of Capricorn, the place from which we firſt began to make our obſervations.

To explain the phenomena that take place in a parallel, direct, and right ſphere.

Take off the globe and it's terminator, and put on in it's place the globe which accompanies the inſtrument and which is furniſhed with a meridian, horizon, and quadrant of altitude; the edge of the horizon, is graduated from the eaſt and weſt, to the north and ſouth points, and within theſe diviſions are the points of the compaſs to the under ſide of this horizon; but at 18 degrees from it another circle is affixed, to repreſent the twilight circle; the meridian is graduated like the meridian of a globe; the quadrant of altitude is divided into degrees, beginning at the zenith, and finiſhing at the horizon.

This globe, if the horizon be differently ſet with reſpect to the ſolar ray, will exhibit the various phenomena ariſing from the ſituation of the horizon with reſpect to the ſun, either in a right, a parallel, or an oblique ſphere; or having ſet the horizon to any place, you will ſee by the central ſolar ray how long the ſun is above or below the horizon of that place, and at what point of the compaſs he riſes, his meridian altitude, and many other curious particulars, of which we ſhall give a few examples.

Set the horizon to coincide with the equator, and place the earth in the firſt point of Libra; then will the globe be in the poſition of a parallel ſphere, and of the inhabitants of the poles at that ſeaſon of the year, which inhabitants are repreſented by the pin at the upper part of the quadrant of altitude; the handle being turned round gently, the earth will revolve upon it's axis, and the ſolar ray will coincide with the horizon, without deviating in the leaſt to the north or ſouth; ſhewing, that on the 21ſt of March the ſun does not appear to riſe or ſet to the terreſtrial poles, but paſſes round through all the points of the compaſs, the plane of the horizon biſecting the ſun's diſk.

Now place the horizon ſo that it may coincide with the poles, and the pin repreſenting an inhabitant be over the equator, the globe in this poſition is ſaid to be in that of a right ſphere; the equator, and all the parallels of latitude, are at right angles, or perpendicular to the horizon; by turning the handle till the earth has completed a year, or one revolution about the ſun, we ſhall perceive all the ſolar phenomena as they happen to an inhabitant of the equator; which are, 1. That the ſun riſes at ſix, and ſets at ſix, throughout the year, ſo that the days and nights there are perpetually equal. 2. That on the 21ſt of March, and 22d of September, the ſun is in the zenith, or exactly over the heads of the inhabitants. 3. That one half of the year, between March and September, the ſun is every day full north, and the other half, between September and March, is full ſouth of the equator, his meridian altitude being never leſs than $66\frac{1}{2}$ degrees.

If the pin repreſenting an inhabitant be now removed out of the equator, and ſet upon any place between it and the poles, the horizon will not then paſs through either of the poles, nor coincide with the equator, but cut it obliquely, one half being above, the other half below the horizon; the globe in this ſtate is ſaid to be in that of an oblique ſphere, of which there are as many varieties as there are places between the equator and either pole. But one example will be ſufficient; for whatever appearance happens to one place, the ſame, as to kind, happens to every other place, differing only in degree, as the latitudes differ. Bring the pin, therefore, over London, then will the horizon repreſent the horizon of London, and in one revolution of the earth round the ſun, we ſhall have all the ſolar appearances through the four ſeaſons clearly exhibited, as they really are in nature; that is, the earth ſtanding at the firſt degree of Libra, and the ſun then entering into Aries, the meridian turned to the ſolar ray, and the hour index ſet to XII, you will then have the globe ſtanding in the ſame poſition towards the ſun, as our earth does at noon on the 21ſt of March. If the handle be turned round, when the ſolar ray comes to the weſtern edge of the horizon, the hour index will point to VI, which ſhews the time of ſun-ſetting; London then paſſes into, and continues in darkneſs, till the hour index having paſſed over XII hours, comes again to VI, at which time the ſolar ray gains the eaſtern edge of the horizon, thereby defining the time of ſun-riſing; ſix hours afterwards the meridian again comes to the ſolar ray, and the hour index points to XII, thereby evidently demonſtrating the equality of the day and night, when the ſun is in the equinoctial. You may then alſo obſerve, that the ſun riſes due eaſt, and ſets due weſt.

Continuing to move the handle, you will find that the ſolar ray declines from the equator towards the north, and every day at noon riſes higher upon the graduations of the meridian than it did before, continually approaching to London, the days at the ſame time growing longer and longer, and the ſun riſing and ſetting more and more towards the north, till the 21ſt of June, when the earth gets in the firſt degree of Capricorn, and the ſun appears in the tropic of Cancer, riſing about 40 minutes paſt III in the morning, and ſetting about 20 min. paſt VIII in the evening; and after continuing about ſeven hours in the nether hemiſphere, appears riſing in the north-eaſt, as before. From the 21ſt of June to the 22d of September, the ſun recedes to the ſouth, and the days gradually decreaſe to the autumnal equinox, when they again become equal.

During the three ſucceeding months, the ſun continues to decline towards the ſouth pole, till the 21ſt of December, when the ſun enters the tropic of Capricorn, riſing to the ſouth-eaſt point of the compaſs about 20 minutes paſt

VIII in the morning, and ſetting about 40 minutes paſt III in the evening, at the ſouth-weſt point upon the horizon; after which, the ſun continues in the dark hemiſphere for 17 hours, and then appears again in the ſouth-eaſt as before. From this chill ſolſtice the ſun returns towards the north, and the days continually increaſe in length till the vernal equinox, when all things are reſtored in the ſame order as at the beginning.

Thus all the varieties of the ſeaſons, the time of ſun-riſing and ſetting, and at what point of the compaſs, as alſo the me idian altitude and declination every day of the year, and duration of twilight, and to what place the ſun is at any time vertical, are fully exemplified by this globe and it's apparatus.

Before we quit the phenomena particularly ariſing from the motion and poſition of the earth, let the globe, with the meridian and horizon, be removed, and the ivory ball which fits upon a pin be placed thereon, to repreſent the earth.

As the axis of this globe ſta nds perpendicular to the plane to the ecliptic, you will find that the ſolar ray continually points to the equator of this little ball, and will never deviate to the north or ſouth; though by turning the handle, the ball is made to complete a revolution round the ſun. This ſhews that the earth in this pofition would have the days and nights equal in every part of the globe, all the year long ; there would have been no difference in the climates of the earth ; no diftinctions of feafons ; an eternal fummer, or never-ceafing winter, would have been our portion ; an unvaried famenefs, that would have limited inquiry, and fatiated curiofity ; and that the variety of the feafons is owing to it's axis being inclined to the plane of it's orbit.

An explanation of the caufes of the viciffitudes of the feafons, fo naturally introduces the following reflections of Mr. Cowper, in his Winter's Walk, that I hope they will not be deemed impertinent, either by the tutor or his pupil.

What prodigies can power divine perform
More grand than it produces year by year,
And all in fight of inattentive man?
Familiar with th' effect we flight the caufe,
And, in the conftancy of nature's courfe,
The regular return of genial months,
And renovation of a faded world,
See nought to wonder at. Should God again,
As once in Gibeon, interrupt the race
Of the undeviating and punctual fun,
How would the world admire! but fpeaks it lefs
An agency divine, to make him know
His moment went to fink, and when to rife,
Age after age, than to arreft his courfe?
All we behold is miracle ; but feen
So duly, all is miracle in vain.

Where now the vital energy that moved,
While fummer was, the pure and fubtle lymph
Through th' impreceptibe meand'ring veins
Of leaf and flower? It fleeps, and th' icy touch
Of unprolific winter has impreſs'd
A cold ftagnation on th' inteftine tide;
But let the months go round, a few fhort months,
And all fhall be reftor'd. Thefe naked fhoots,
Barren as lances, among which the wind
Makes wintry mufic, fighing as it goes,
Shall put their graceful foliage on again;
And more afpiring, and with ampler fpread,
Shall boaft new charms, and more than they have loft.

* * * * * * *

And all this uniform, uncoulour'd fcene
Shall be difmantled of it's fleecy load,
And flufh into variety again,
From dearth to plenty, and from death to life,
Is nature's progrefs when fhe lectures man
In heavenly truth; evincing, as fhe makes
The grand tranfition, that there lives and works
A foul in all things, and that foul is God.
The beauties of the wildernefs are his,
That makes fo gay the folitary place,
Where no eyes fees them. And the fairer forms,
That cultivation glories in, are his.
He fets the bright proceffion on it's way,
And marfhals all the order of the year.

* * * * * * *

He feeds the fecret fire
By which the mighty procefs is maintain'd:
Who fleeps not, is not weary; in whofe fight
Slow circling ages are as tranfient days;
Whofe work is without labour; whofe defigns
No flaw deforms, no difficulty thwarts;
And whofe beneficence no change exhaufts.

Of the Lunarium, Fig. 2, Plate XII.

Having thus illuftrated the phenomena, which arife particularly from the inclination of the earth's axis to the plane of the ecliptic, from it's rotation round it's axis, and revolution round the fun; I now proceed to explain, by this inftrument, the phenomena of the moon. But in order to this, it will be neceffary to fpeak firft of the inftrument, which is put in motion, like the preceding one, by the teeth on the fixed wheel; it is alfo to be placed upon the fame focket as the tellurian, and confined down by the fame milled nut.

The floping ring P Q reprefents the plane of the moon's orbit, or path, round the earth; fo that the moon in her revolution round the earth does not move parallel to the plane of the ecliptic, but on this inclined plane; the two points of this plane, that are connected by the brafs wire, are the nodes, one of which is marked ☊, for the afcending node, the other ☋ for the defcending node. The moon is therefore fometimes on the north, and fometimes on the fouth fide of the ecliptic, which deviations from the ecliptic are called her north or fouth latitude; her greateft deviation, which is when fhe is at her higheft and loweft points, called her limits, is 5 deg. 18min.; this with all the other intermediate degrees of latitude, are engraved on this ring, beginning at the nodes, and numbered both ways from them. At each ſide of the nodes, and at about 18 degrees diſtant from them, we find this mark ☉, and at about 12 degrees this ☽, to indicate that when the full moon is got as far from the nodes as the mark ☽, there can be no eclipſe of the moon, nor any eclipſe of the ſun; when the new moon has paſſed the mark ○, theſe points are generally termed the limits of eclipſes. The nodes of the moon do not remain fixed at the ſame point of the ecliptic, but have a motion contrary to the order of the ſigns.

T V is a ſmall circle parallel to the ecliptic; it is divided into 12 ſigns, and each ſign into 30 degrees; this circle is moveable in it's ſocket, and is to be ſet by hand, ſo that the ſame ſign may be oppoſite to the ſun, that is marked out by the annual index. Theſe ſigns always keep parallel to themſelves, as they go round the ſun; but the inclined plane with it's nodes go backwards, ſo that each node recedes through all the above ſigns in about 19 years. R S is a circle, on which are divided the days of the moon's age; X Y is an ellipſis, to repreſent the moon's elliptical orbit, the direct motion of the apogee, or the line of the apſides, with the ſituation of the elliptical orbit of the moon, and place of the apogee in the ecliptic at all times.

To rectify the lunarium.

Set the annual index on the large ecliptic, to the firſt of Capricorn ; then turn the plate, with the moon's ſigns upon it, until the beginning of Capricorn points directly at the ſun ; turn the handle till the annual index comes to the firſt of January; then find the place of the north node in an ephemeris, to which place among the moon's ſigns, ſet the north node of her inclined orbit, by turning it till it is in it's proper place in the circle of ſigns ; ſet the moon to the day of her age.

GENERAL PHENOMENA OF THE MOON.

Having rectified the lunarium for uſe, on putting it into motion it will be evident,

1. That the moon, by the mechaniſm of the inſtrument, always moves in an orbit inclined to that of the ecliptic, and conſequently in an orbit analogous to that in which the moon moves in the heavens.

2. That ſhe moves from weſt to eaſt.

3. That the white or illuminated face of the moon is always turned towards the ſun.

4. That the nodes have a revolution con-

trary to the order of the figns, that is, from Aries to Pifces; that this revolution is performed in about nineteen years, as in nature.

5. That the moon's rotation upon her axis is effected and completed in about $27\frac{1}{2}$ days, whereas it is $29\frac{1}{2}$ days from one conjunction with the fun to the next.

6. That every part of the moon is turned to the fun, in the fpace of her monthly or periodic revolution.

To be more particular. On turning the handle, you will obferve another motion of the earth, which has not yet been fpoken of, namely, it's monthly motion about the common center of gravity between the earth and moon, which center of gravity is reprefented by the pin *Z*. From hence we learn, that it is not the center of the earth which defcribes what is called the annual orbit, but the center of gravity between the earth and moon, and that the earth has an irregular, vermicular, or fpiral motion about this center, fo that it is every month at one time nearer to, at another further from the fun. It is evident from the inftrument, that the moon does not regard the center of the earth, but the center of gravity, as the center of her proper motion; that the center of the earth is furtheft from the fun at new moon, and neareft at the full moon; that in the quadratures the monthly parallax of the earth is ſo ſenſible, as to require a particular equation in aſtronomical tables. Theſe particulars were firſt applied to the orrery, by the late ingenious Mr. Benjamin Martin.

To explain the phaſes of the moon.

The moon aſſumes different phaſes to us, 1. on account of her globular figure; 2. on account of the motion in her orbit, between the earth and the ſun, for whenever the moon is between the earth and the ſun, we call it new moon, the enlightened part being then turned from us; but when the earth is between the ſun and the moon, we then call it full moon, the whole of the enlightened part being then turned towards us.

The phaſes of the moon are clearly exhibited in this inſtrument; for we here ſee that half which is oppoſite to the ſun is always dark, while that which is next to the ſun is white, to repreſent the illuminated part. Thus, when it is new moon, you will ſee the whole white part next the ſun, and the dark part turned towards the earth, ſhewing thereby it's diſappearance, or the time of it's conjunction and change: on turning the handle, a ſmall portion of the white part will begin to be ſeen from the earth, which portion will increaſe towards the end of the 7th day, when you will perceive that half of the light, and half of the dark ſide, is turned towards the earth, thus illuſtrating the appearance of the moon at the firſt quarter. From hence the light ſide will continually ſhew itſelf more and more in the gibbous form, till at the end of fourteen days the whole white ſide will be turned towards the earth, and the dark ſide from it, the earth now ſtanding in a line between the ſun and moon; and thus the inſtrument explains the oppoſition, or full moon. On turning the handle again, ſome of the ſhaded part will begin to turn towards the earth, and the white ſide to turn away from it, decreaſing in a gibbous form till the laſt quarter, when the moon will appear again as a creſcent, which ſhe preſerves till ſhe has attained another conjunction.

In this lunarium the moon has always the ſame face or ſide to the earth, as is evident from the ſpots delineated on the ſurface of the ivory ball, revolving about it's axis in the courſe of one revolution round the earth; in conſequence of which the light and dark parts of the moon appear permanent to us, and the phaſes are ſhewn as they appear in the heavens.

The tutor will be enabled by this inſtrument to explain ſome other circumſtances to his pupil; namely, that as the earth turnsr ound it's axis once in 24 hours, it muſt in that time exhibit every part of it's ſurface to the inhabitants of the moon, and therefore it's luminous and opake parts will be feen by them in conftant rotation. As that half of the earth which is oppofed to the fun is always dark, the earth will exhibit the fame phafes to the lunarians that we do to them, only in a contrary order, that when the moon is new to us, we fhall be full to them, and *vice verfa*. But as one hemifphere only of the moon is ever turned towards us, it is only thofe that are in this hemifphere who can fee us; our earth will appear to them always in one place, or fixed in the fame part of the heavens: the lunarians in the oppofite hemifphere never fee our earth, nor do we ever view that part of the moon which they inhabit. The moon's apparent diurnal motion in the heavens is produced by the daily revolution of our earth.

If we confider the moon with refpect to the fun, the inftrument fhews plainly that one half of her globe is always enlightened by the fun; that every part of the lunar ball is turned to the fun, in the fpace of her monthly or periodic revolution; and that therefore the length of the day and night in the moon is always the fame, and equal to $14\frac{3}{4}$ of our day. When the fun fets to the lunarians in that hemifphere next the earth, the terreftrial moon rifes to them; and they can therefore never have any dark night ; while thofe on the other hemifphere can have no light by night, but what the ftars afford.

Of the periodical and fynodical month.

The difference between the periodical month, in which the moon exactly defcribes the ecliptic, and the fynodical, or time between any two new moons, is here rendered very evident. To fhew this difference, obferve at any new moon her place in the ecliptic, then turn the handle, and when the moon has got to the fame point in the ecliptic, you will fee that the dial fhews $27\frac{1}{3}$ days, and the moon has finifhed her periodic revolution. But the earth at the fame time having advanced in it's annual path about 27 degrees of the ecliptic, the moon will not have got round in a direct line with the fun, but will require 28 days and 4 hours more, to bring it into conjunction with the fun again.

Of eclipfes of the fun and moon.

There is nothing in aftronomy more worthy of our contemplation, nor any thing more fublime in natural knowledge, than rightly to comprehend thofe fudden obfcurations of the heavenly bodies that are termed eclipfes, and the accuracy with which they are now foretold. "One of the chief advantages derived by the prefent generation, from the improvement and diffufion of philofophy, is delivery from unneceffary terror, and exemption from falfe alarms. The unufual appearances, whether regular or accidental, which once fpread confternation over ages of ignorance, are now the recreations of inquifitive fecurity. The fun is no more lamented when it is eclipfed, than when it fets; and meteors play their corrufcations without prognoftic or prediction."

I have already obferved, that the fun is the only real luminary in the folar fyftem, and that none of the other planets emit any light but what they have received from the fun; that the hemifphere which is turned towards the fun is illuminated by his rays, while the other fide is involved in darknefs, and projects a fhadow, which arifes from the luminous body.

When the fhadow of the earth falls upon the moon, it caufes an eclipfe of the moon; when the fhadow of the moon falls upon the earth, it caufes an eclipfe of the fun.

An eclipfe of the moon, therefore, never happens but when the earth's opake body interpofes between the fun and the moon, that is, at the full moon; and an eclipfe of the fun never happens but when the moon comes in a line between the earth and the ſun, that is, at the new moon.

From what we have already ſeen by the inſtrument, it appears that the moon is once every month in conjunction, and once in oppoſition; from hence it would appear, that there ought to be two eclipſes, one of the ſun, the other of the moon, every month; but this is not the caſe, and for two reaſons, firſt, becauſe the orbit of the moon is inclined in an angle of about 5 degrees to the plane of the ecliptic; and ſecondly, becauſe the nodes of this orbit have a progreſſive motion, which cauſes them to change their place every lunation. Hence it often happens, that at the times of oppoſition or conjunction, the moon has ſo much latitude, or, what is the ſame thing, is ſo much below or above the plane of the ecliptic, that the light of the ſun will in the firſt caſe reach the moon, without any obſtacle, and in the other the earth; but as the nodes are not fixed, but run ſucceſſively through all the ſigns of the ecliptic, the moon is often, both at the times of conjunction and oppoſition, in or very near the plane of the ecliptic; in theſe caſes an eclipſe happens, either of the ſun or moon, according to her ſituation. The whole of this is rendered clear by the lunarium, where the wire projecting from the earth ſhews when the moon is above, below, or even with the earth, at the times of conjunction and oppofition, and thus when there will be, or not, any eclipfes.

The diftance of the moon from the earth varies fenfibly with refpect to the fun; it does not move in a circular, but in an elliptic orbit round us, the earth being at one of the foci of this curve.* The longer axis of the lunar orbit is not always directed to the fame point of the heavens, but has a movement of it's own, which is not to be confounded with that of the nodes; for the motion of the laft is contrary to the order of figns, but that of the line of apfides is in the fame direction, and returns to the fame point in the heavens in about nine years. This motion is illuftrated in the lunarium by means of the brafs ellipfis X Y, which is carried round the earth in little lefs than nine years: thus fhewing the fituation of the elliptical orbit of the moon, and the place of the apogee in the ecliptic.

Thofe who wifh to extend the application of the inftrument further, may have an apparatus applied to it for explaining the Jovian and Saturnian fyftems, illuftrating the motion

* That point of her orbit wherein fhe is neareft the earth is called her *perigee*; the oppofite point, in which fhe is fartheft off, is called her *apogee*. Thefe two points are called her *apfides*, the apogee is the higher, the perigee the lower apfis.

of their ſatellites, and of the ring of Saturn. But as this application would extend the price of the inſtrument beyond the reach of moſt purchaſers, I have thought it would be unneceſſary to deſcribe them; the more ſo, as the phenomena they are intended to explain are accurately and clearly deſcribed in ſeveral introductory works of aſtronomy.

Having ſurveyed and endeavoured to illuſtrate the general phenomena of the heavens, let us turn the mental eye towards our Lord, who hath made all things in heaven and earth, and whoſe tender care is over all.

" Innumerable worlds ſtood forth at thy command, and by thy word they are filled with glorious works.

" Who can comprehend the boundleſs univerſe? or number the ſtars of heaven?

" Amidſt them thou haſt provided a dwelling for man, that he might praiſe thy name.

" The ſun ſhineth, and is very glorious, and we rejoice in the light thereof.

" We admire it's brightneſs, and perceive it's greatneſs; and our earth vaniſhes in compariſon with it.

" Many worlds are nouriſhed by it, and it's glory is great. By it's influence the earth is cloathed with plenty, and the habitation of man rendered exceeding beautiful.

" Yet what is this amidſt thy works? is it not as a point, and as nothing in the firmament of heaven?

" What then is man, that thou art mindful of him, or the ſon of man, that thou viſiteſt him?

" Thy power is circumſcribed by no bounds, both great and ſmall are alike unto thee.

" From the ſun in the firmament of heaven, to the ſand on the ſea-ſhore, all is the operation of thy hand.

" From the cherubim and ſeraphim which ſtand before thee, to the worm in the bowels of the earth, all living creatures receive of thee what is good and expedient for them."*

Praiſe then the Lord, O my ſoul, praiſe his name for ever and ever.

* See " Hymns to the Supreme Being, in imitation of the Eaſtern Songs." London, 1780.

ESSAY IV.

AN

INTRODUCTION

TO

Practical Astronomy.

THERE is no part of mathematical ſcience more truly calculated to intereſt and ſurprize mankind, than the meaſurement of the relative poſitions and diſtances of *inacceſſible* objects.

To determine the *diſtance* of a ſhip ſeen on a remote ſpot of the unvaried face of the ocean, to aſcertain the *height* of the clouds and meteors which float in the inviſible fluid above our heads, or to ſhew with certainty the *dimenſions* of the ſun, and other bodies, in the heavens, are among the numerous problems which to the vulgar appear far beyond the reach of human art, but which are nevertheleſs truly reſolved by the incontrovertible principles of the *mathematics*.

Theſe principles, ſimple in themſelves, and eaſy to be underſtood, are applied to the conſtruction of a variety of inſtruments; and the following pages contain an account of their uſe in the *quadrant* and the *equatorial*.

The poſition of any object, with regard to a ſpectator, can be conſidered in no more than two ways; namely, *as to it's diſtance*, or the length of a line ſuppoſed to be drawn from the eye to the object; and *as to it's direction*, or the ſituation of that line with reſpect to any other lines of direction; or, in other words, whether it lies to the right or left, above or below thoſe lines. The firſt of theſe two modes bears relation to a *line* abſolutely conſidered, and the ſecond to an *angle*. It is evident that the diſtance can be directly come at by no other means than by meaſuring it, or ſucceſſively applying ſome known meaſure along the line in queſtion; and therefore, that in many caſes the diſtance cannot be directly found; but the poſition of the line, or the angle it forms, with ſome other aſſumed line, may be readily aſcertained, provided this laſt line do likewiſe terminate in the eye of the ſpectator. Now the whole artifice of meaſuring inacceſſible diſtances conſiſts in finding their lengths, from the conſideration of angles, obſerved about ſome other line, whoſe length can be ſubmitted to actual menfuration. How this is done, I fhall proceed to fhew.

Every one knows the form of a common pair of compaffes. If the legs of this inftrument were mathematical lines, they would form an angle greater or lefs, in proportion to the fpace the points would have paffed through in their opening. Suppofe an arc of a circle to be placed in fuch a manner, as to be paffed over by thefe points, then the angles will be in proportion to the parts of the arc paffed over; and if the whole circle be divided into any number of equal parts, as for example 360, the number of thefe comprehended between the points of the compaffes, will denote the magnitude of the angle. This is fufficiently clear; but there is another circumftance which beginners are not often fufficiently aware of, and which therefore requires to be well attended to: it is, that the angle will be neither enlarged nor diminifhed by any change in the length of the legs, provided their pofition remains unaltered; becaufe it is the inclination of the legs, (and not their length,) or the fpace between them, which conftitutes the angle. So that if a pair of compaffes, with very long legs, were opened to the fame angle as another fmaller pair, the intervals between their refpective points would be very different, but the number of degrees on the circles, fuppofed to be applied to each, would be equal, becaufe the degrees themfelves on the fmaller circle would be exactly proportioned to the fhortnefs of the legs. This property renders the admeafurement of angles very eafy, becaufe the diameter of the meafuring circle may be varied at pleafure, as convenience requires.

In practice, however, the magnitude of inftruments is limited on each fide. If they are made very large, they are difficult to manage; and their weight, bearing a high proportion to their ftrength, renders them liable to change their figure, by bending, when their pofition is altered: but, on the contrary, if they are very fmall, the errors of conftruction and graduation amount to more confiderable parts of the divifions on the limb of the inftrument.

General Principles of Calculation.

Before we proceed any further, I fhall flightly notice the general principles of the calculations we are going to ufe.

Plane trigonometry is the art of meafuring and computing the fides of plane triangles, or of fuch whofe fides are right lines.

In moft cafes of practice, it is required to find lines or angles whofe actual admeafurement is difficult or impracticable. Thefe mathematicians teach us to difcover by the relation they bear to other given lines or angles, and proper methods of calculation.

Finding the comparifon of one *right line* with another *right line*, more eafy than the comparifon of a *right line* with a *curve;* they meafure the quantities of the angles not by the arc itfelf, which is defcribed on the angular point, but by certain lines defcribed about that point.

If any *three* parts of a triangle are *known*, the remaining unknown parts may be found either by *conftruction* or by *calculation*.

If *two angles* of a triangle are known in degrees and minutes, the *third* is found by fubtracting their fum from 180 degrees; but if the triangle be right-angled, either angle in degrees, taken from 90 degrees, gives the other angle.

Before the required fide of a triangle can be found by calculation, it's oppofite angle muft be given or found.

The required part of a triangle muft be the laft of four proportionals, written in order one under the other, whereof the three firft terms are given or known.

Againft the three firft terms of the proportion, are to be written the correfponding numbers taken from tables which have been conftructed to facilitate calculation.

Thefe tables are called *logarithms ;* and are fo contrived, that *multiplication* is performed by *addition*, and *divifion* by *fubtraction.*

If the value, then, of the firft term of your proportion be taken from the fum of the fecond and third, you obtain the value of the fourth, or quantity required ; becaufe the addition and fubtraction of logarithms correfponds with the multiplication and divifion of natural numbers.

To avoid even the fubtraction of the firft term, when radius is not one of the proportionals, fome chufe to add the *arithmetical complement.*

To find the arithmetical complement of a logarithm, begin at the left hand, and write down what each figure wants of 9, and what the laft figure wants of 10. The number thus found is to be added to the fecond and third values ; the fum, rejecting the borrowed index, is the tabular number expreffing the quantity required : thus the arithmetical complement of 2.6963564 is 7.3036436.

To find the logarithm of a given number. Here you muft remember that the *integral* part of a logarithm is called it's *index*, becaufe it denotes the number of figures in the natural number anfwering to the logarithm. The *decimal* part of every logarithm belongs equally to a whole number, a mixed number, or a decimal number; that is, they are expreſſed by the ſame figures, in the ſame order, but the index varies according to the value of the expreſſion. The index of a logarithm is always an unit leſs than the number of figures in the integer number, of which it is the logarithm.

Hence the following general rule for finding the index of a logarithm. To the left of the logarithm, write that figure or figures which expreſſes the diſtance from unity, of the higheſt place digit in the given number, reckoning the units place 0, the next place 1, the next to that 2, the next to that 3, &c.

By attending to the following example, it will be eaſy for you to find the logarithm of a given number, and the number correſponding to a given logarithm.

Thus let the number be 7854. One column gives the decimal part; the next the logarithm completed with the indexes.

Number.	Decim. Part.	Complete Log.
7854	0.895091	3.895091
785.4	0.895091	2.895091
78.54	0.895091	1.895091
7.854	0.895091	0.895091
0.7854	0.895091	$\bar{1}.895091$
0.07854	0.895091	$\bar{2}.895091$

Tables of logarithms are alſo conſtructed for ſines, tangents, &c. of an arc: theſe are to be taken out from the tables, according to their reſpective value.

Spherical trigonometry is the ſcience of calculating the triangles formed on the ſurface of a globe, by three arches of *great* circles: the ſmaller circles of a ſphere are not noticed in the calculations of a ſpherical trigonometry. This ſcience is too intricate to be any way explained in this eſſay; we muſt therefore content ourſelves with only giving the proportions neceſſary to anſwer our purpoſe.

Of the Quadrant, and it's Uses.

Every circle being ſuppoſed to be divided into 360 equal parts, or degrees, it is evident that 90 degrees, or one-fourth part of a circle, will be ſufficient to meaſure all angles formed between a line perpendicular to the horizon, and other lines which are not directed to points below the level. Fig. 1, pl. XIV, is a drawing of a very ſimple and uſeful inſtrument of this kind. A B C is a quadrant mounted upon an axis and pedeſtal: by means of the axis, it may be immediately placed in any vertical poſition, and the pedeſtal being moveable in the axis of the circle E F, ſerves to place it in the direction of any azimuth, or towards any point of the compaſs. The limb A B is divided into degrees and halves, numbered from A; and upon the radius B C are fixed two ſights, of which B is perforated with a ſmall hole, and is provided with a dark glaſs, to defend the eye from the ſun's light; and the other ſight C has a larger hole, furniſhed with croſs wires, and alſo a ſmaller, which is of uſe to take the ſun's altitude by the projection of the bright image of that luminary upon the oppoſite ſight. From the center C hangs a plumb-line C P. The horizontal circle F E is divided into four quadrants of 90 degrees; and an arm E, connected with the pedeſtal, moves along the limb, and conſequently ſhews the poſition of the plane of the quadrant, as will hereafter be more minutely explained. Laſtly, the ſcrews G, H, I, render it very eaſy to ſet the whole inſtrument ſteadily and accurately in it's proper poſition, notwithſtanding any irregularity in the table or ſtand it may be placed upon.

The rationale of this inſtrument is very clear and obvious. It is uſed to meaſure the angular diſtance of any body, or appearance, either from the zenith or point immediately above our heads, or from the horizon or level. The plumb-line C P, if continued upwards from C, would be directed to the zenith Z; and the line C L, ſuppoſed to be drawn from the center of the quadrant to an object L, will form an angle L C Z, which is the zenith diſtance, and is equal to the angle B C P, formed between the oppoſite parts of the ſame lines. We ſee, therefore, that the degrees on the arc, comprehended on the limb of the quadrant, between the plumb-line and the extremities next the eye, meaſure the angle of zenith diſtance.

Again, the line C K (forming a right angle with the perpendicular C Z) is level, or horizontal; the angle L C K muſt therefore be the altitude or elevation of L above the horizon; and this laſt angle muſt be equal to the angle meaſured between the plumb-line and the end A fartheſt from the eye; becauſe both theſe are equal to the quantity which would be left, after taking the zenith diſtance from a right angle, or the whole quadrant.

The determination of the altitude or zenith diſtance of an object is not ſufficient to aſcertain it's place, becauſe the object may be placed in any direction with reſpect to azimuth, or the points of the compaſs, without increaſe or diminution of it's altitude. Hence it is that an horizontal graduated circle is a neceſſary addition to a quadrant which is not intended to be always uſed in the ſame plane. The bearing or poſition of an object relative to the cardinal points, together with the altitude, is ſufficient to aſcertain the place of any object or phenomenon.

After this ſhort account of the general principles of the quadrant, I ſhall proceed to ſhew ſome of the leading problems reſolved by it.

Problem I.

To adjuſt the quadrant for obſervation.

The quadrant is adjuſted for obſervation, when it's plane continues perpendicular to the horizon in all poſitions in the line of ſight.

To effect this, bring the index to 90° on the horizontal circle, and turn one or both of the ſcrews which are fixed oppoſite 60°, till the plumb-line lightly touches the plane of the quadrant; then turn the index to 0°, and make the ſame adjuſtment by means of the ſcrew at 0°, and the quadrant is ready for obſervation.

Or otherwiſe; ſet the index at 0°, and obſerve the degree marked by the plumb-line on the limb; then turn the index to the other 0°, which is diametrically oppoſite, and obſerve the degree marked by the plumb-line: if it be the ſame as before, there will be no occaſion to alter the ſcrews at 60°; but if otherwiſe, one or both of thoſe ſcrews muſt be turned, till the plumb-line interſects the middle degree, or part, between the two. After this operation, the degree marked by the plumb-line muſt be obſerved, as before, by ſetting the index at both the 90°, and the adjuſtment of the plumb-line to the middle diſtance muſt be made by the ſcrew at 0°, taking care not to touch the other ſcrews.

The latter method of adjuſtment, being more accurate in practice, may be uſed after the former.

The larger or more expenſive inſtruments have apparatus for ſetting the axis of motion at right angles to the planes of the horizontal circle and quadrant, the line of ſight or collimation parallel to the radius paſſing through 90°, &c. &c. In ſmall inſtruments, theſe adjuſtments are made by the workman.

INTRODUCTORY PROBLEMS.

PROBLEM II.

To find the diſtance of an object on the earth, by obſervations made from two ſtations on the ſame level.

OBSERVATIONS.

Chuſe two ſtations, between which the ground is level, and place a viſible mark on each. The diſtance between them ought not to be leſs than the ſeventh or eighth part of the eſtimated diſtance of the objects, and neither ſtation ought to be conſiderably nearer the object than the other. Meaſure the diſtance between the ſtations, by means of meaſuring poles, a chain, or a piece of ſtretched cord. From one ſtation direct the quadrant to the object, by looking through the hole in one ſight, and moving the upright axis about, till the object is ſeen through the hole in the other, exactly at the interſection of the croſs wires. Obſerve the degrees and parts ſhewn by the index on the horizontal circle, then direct the quadrant in the ſame manner to the mark of the other ſtation, and obſerve the degrees and parts ſhewn by the index. The number of degrees and parts intercepted between this and the former poſition of the index, is the angle at the firſt ſtation. The ſame operations repeated at the ſecond ſtation, will give the angle at that ſtation.

Thus let F, fig. 1, plate XV, be the object, A, B, the two ſtations 880 feet diſtant from each other; the angle obſerved at A found to be 83° 45′, that obſerved at B 85° 15.

Solution. Take the ſum of the two obſerved angles from 180°, and the remainder will be the angle under which the two ſtation-marks would be ſeen from the object. Let F be the object, A and B the two ſtations, the angle at A found by obſervation to be 83° 45′, that at B 85° 15′, the ſum of theſe two angles is 169°, which, taken from 180°, gives 11° for the value of angle F.

Then as the ſine of angle F, at the object -	11° 00′	9.2805988
Is to the ſine of angle A at one ſtation A -	83° 45′	9.9974110
So is the diſtance A B between the ſtations	880	2.9444827
To the diſtance of the object B F from the other ſtation -	4584.5 feet	3.6612949

Solution of the problem by protraction. From a ſcale of equal parts, lay down a right line to repreſent the meaſured baſe. By means of the protractor, or by the line of chords, draw a line from each extremity of the baſe, forming angles equal to thoſe actually obſerved; continue theſe lines till they interſect.

The interval between the point of interſection at one extremity of the baſe being taken between the compaſſes, and applied to the line of equal parts, will ſhew the diſtance between the object and the ſtation repreſented by that extremity.

This problem may, in caſes of ſmall diſtance, be conveniently applied to a baſe line meaſured within a room, and the obſervation taken out at the windows.

486

PROBLEM III.

To find the height of a ſpire, a mountain, or any other elevation.

Caſe 1. When the diſtance DE, fig. 2, plate XV, of the point F immediately beneath the object can be meaſured.*

Obſerve the angle of altitude CDE with the quadrant, by viewing the ſummit through the ſights, and noting the degrees and parts indicated by the interſection of the plumb-line; meaſure alſo the horizontal diſtance; let the angle CDE be 47° 30′, the line DE 100 feet.

Then as radius - -	10.0000000
To the tangent of ∠ CDE 47 30′	10.0379475
So is the meaſured diſtance DE 100	2.0000000
To the height required, 109.5 -	2.0379475

Or by conſtruction. Draw a right line equal to the meaſured baſe, taken from a ſcale of equal parts.

Erect a perpendicular from one extremity, and from the other draw a line inclined towards the perpendicular, and forming an angle with the baſe, equal to the obſerved angle.

The interval between the interſection of this laſt line, and the perpendicular, and the lower extremity of the perpendicular itſelf,

* As the point cannot conveniently be taken from the ground, you muſt add the height of the eye at the obſervation, to the height found.

being taken in the compaſſes, and applied to the line of equal parts, will ſhew the height required.

Caſe 2. When the diſtance of the point A immediately beneath the ſummit cannot be meaſured.

Find the diſtance by prob. ii, and the height by caſe 1, of this problem.

Or otherwiſe meaſure a baſe line D C, fig. 3, plate XV, directly towards the object, and take the altitude from each end of the baſe.

Let D C, the baſe, be 100 feet, the angle obſerved at C 32°, the angle at D 58°; ſubtract the leſſer altitude from the greater, and the difference is the angle B 26°.

Then as the ſine of this difference 26° - -	9.6418420
Is to the ſine of the leſſer altitude 32° - -	9.7242097
So is the baſe line 100 -	2.0000000
To the direct diſtance between the ſummit and nearer end of the baſe line - -	2.0823677
And,	
As radius or angle A 90° -	10.
Is to the ſine of the greater altitude 58° - -	9.9284205
So is the diſtance laſt found	2.0823677
To the height required, 102.51 feet	2.0107822

Or by conſtruction. Set off the baſe line, and from it's extremities draw lines inclined to the baſe in the reſpective angles obſerved, but in ſuch a manner, as that the leſs angle may be formed by the baſe itſelf, and the greateſt by the prolongation of the baſe.

Theſe lines will interſect.

From the point of interſection let fall a perpendicular on the prolongation of the baſe, and it will give the height required.

The firſt method of ſolving this caſe is in general the beſt in practice. It is for the moſt part much more eaſy to find a baſe ſufficiently long and level between two ſtations, nearly equi-diſtant from the eminence, as the firſt requires, than in a direction towards it, becauſe the ground uſually riſes irregularly towards mountains. And in the latter caſe alſo, if the difference between the two altitudes be not very conſiderable, the reſult will be rendered erroneous by a very ſmall inaccuracy of obſervation.

Problem IV.

To plot a field by a baſe line meaſured within the field.

Set up marks in the corner of a field, and meaſure a line in the field in ſuch a direction, as that it may be ſet as far as poſſible from pointing towards any of the angles.

Direct the ſights from one end of the baſe to each of the angles ſucceſſively, and alſo to the other extremity of the baſe, carefully noting the degrees and parts of the horizontal circle marked out by the index. Repeat the like operations at the other end of the baſe line.

Conſtruction. Draw a faint line upon paper, upon which ſet off from a ſcale of equal parts the meaſured baſe. From it's extremities draw lines, forming the reſpective angles obſerved. The interſections of thoſe lines will ſhew the corners, or angles, of the field, and muſt be joined by right lines.

This problem being nothing more than a determination of the poſition of the angular points with reſpect to the baſe line, by prob. ii, will be more accurate in practice, the more nearly the conditions there expreſſed are adhered to. If a baſe line cannot be had in view of all the angles, and in a convenient poſition, two or more baſe lines may be meaſured, and connected together by the obſervation of the requiſite angles; or the three ſides of a triangle may be meaſured in the field, according to the diſcretion of the ingenious learner, and the bearings of the corners of the field taken from ſuch extremities of any of theſe meaſured lines as are beſt adapted to the purpoſe.

As this method is far from being laborious, the ſtudent will do well to meaſure the field twice, but from a different baſe each time.

It may be proper to obſerve, for the uſe of ſuch as are unacquainted with ſurveying of land, that the Engliſh acre is 4840 ſquare yards, and that land is moſt conveniently meaſured by the Gunter's chain, of 22 yards in length, divided into 100 links; becauſe the ſquare chain, or 22 multiplied by 22, equal to 484, is exactly the tenth part of an acre. If the plot of a field meaſured in chains and links be therefore made upon paper, and divided into a number of triangles, by drawing right lines within it, the baſe and perpendicular of each triangle may be meaſured from the ſcale of equal parts, and half their product will be the area of the triangle in ſquare chains; the ſum of all the areas of the triangles will be the area of the field; which divided by 10, will ſhew the number of acres; the remaining decimal fraction multiplied by 4, gives the roods; and the decimal part of this laſt product multiplied by 40, gives the perches.

In the following example is a more ready method of obtaining the contents.

Example. Let A B C D E F, fig. 4, pl. XV, be the field, in which I aſſumed two ſtations, P, Q, at the diſtance of 10 chains from each other.

From P, I obferved the following angles: Q P A to be 21° 20′; A B P 49° 10′; B P C 57° 12′; C P D 29° 40′; D P E 64° 25′; E P F 79° 16′.

From the ftation Q, I obferved the following angles: P Q D 10° 40′; D Q C 18° 30′; C Q B 42° 00′; B Q A 67° 05′. A Q F is equal to A Q O added to E Q O; that is, 137°; F Q E 62° 52′.

Solution. Conftruct the figure as directed, and divide it into two trapeziums, D C B A, and D E F A; then apply the perpendiculars Q C, H B, L D, I F, and the diagonals B D, A E, and the fide A D, to a fcale of equal parts, and you will obtain the area near the truth.* But it may be obtained accurately by

Trigonometry.

1. In the triangle A Q B you will find Q A 10.428, Q B 15.198, and the angle A Q B 67° 5′.

2. In the triangle B P Q, you find Q B 15.198, B P 15.259, the angle B P Q 38° 20′.

3. In the triangle Q P C we have P C 12.404, P B 15.259, angle B P C 57° 12′.

4. In the triangle Q P D we find P D 8.941, P C 12.404, C P B 29° 40′.

5. In the triangle Q P F we have P E 10.950, P D 8.941, angle D P E 64° 25′.

* The angles are in fome inftances in this example affumed too oblique to be afcertained with accuracy in practice, but anfwer fully the purpofe of illuftration.

6. In the triangle P Q F we obtain P F equal 16.820, Q F 14.471, angle P F Q 36° 18′.

7. In the triangle E P F, P E is 10.950, P F 16.820, angle E P F 79° 16′.

8. In the triangle A Q F, Q F is 14.471, A Q 10.428, angle A Q F 137°.

Now writers on menſuration have ſhewn, that if you add the logarithms of the two ſides of a triangle and the included angle together, the ſum, rejecting radius, will be the logarithm of double the area of that triangle. By this method we find,

1. the double area of △	A Q B	to be	145.984
2. - - -	B P Q	—	143.844
3. - - -	B P C	—	159.143
4. - - -	C P D	—	54.895
5. - - -	D P E	—	88.304
6. - - -	P F Q	—	144.105
7. - - -	E P F	—	180.964
8. - - -	A Q F	—	102.916
Divide by 2)			1020.155
			510.077

The young ſtudent in trigonometry will find the ſolution of this problem no contemptible exerciſe; he may likewiſe, if he has a ſufficient degree of patience aud induſtry, find every line drawn in the figure.

Problem v.

To plot a field, by meaſuring the ſides and angles.

Set up marks at each of the angles, and at every one of theſe marks direct the quadrant to the two adjacent marks on each ſide. The number of degrees and parts between the two poſitions of the index on the horizontal circle, will ſhew the angle at the ſtation where the obſervation is made. Meaſure the diſtance to the next ſtation, and obſerve the angle there in the ſame manner. And thus proceed completely round the field.

Conſtruction. From the ſcale of equal parts draw a line equal to the firſt meaſured ſide, and from it's extremities draw two lines, forming angles equal to thoſe actually obſerved.

Make theſe laſt lines equal to the ſides they repreſent, and from their extremities draw two other lines at angles reſpectively found by obſervation.

Proceed thus till the whole field is plotted.

When all the angles of a field are thus meaſured, their ſum, if the operation has been truly made, will be equal to twice as many right angles, deducting four, as there are angles in all, provided they be all inward angles. But if any of them be outward angles, their refpective fupplements to 360° muft be taken in making up the fum inftead of the angles themfelves. When the fum proves either greater or lefs than juft the figure, it will not anfwer on paper; and as obfervations made with fmall inftruments cannot be expected to be free from perceptible errors, it will be expedient to correct the angles by adding or fubtracting fuch defect or excefs, to or from all the angles, in proportion to their magnitude, or more readily in equal proportions among them.

This way of meafuring is much ufed in America, by the meafuring wheel and mariner's compafs, and is applicable to extenfive woody or mountainous tracts of land, where great accuracy is not required. It may alfo be ufed in conjunction with other methods, for delineating a fea-coaft, &c.

The following example will fhew how you may obtain the contents of the field.

Example. In furveying the field A B C D E, fig. 5, plate XV, I obferved at A the angle F A E to be 51° 13′, at B the angle C B G was 69° 30′, at C the angle A C B was 39° 7′, and the angle A C D 78° 35′; at D the angle E D H was 88° 40′ and at E the angle C E A 54° 20′; the fide A B meafured 1940 links, B C 1555, C D 2125, D E 2741, and E A 1624. We have now to find the area of the field.

Subtract the angle C B C 69° 30′ from 180°, and you have the angle C A B 110 30′; to which if you add the angle A C B 39° 7′, and subtract this sum from 180, you obtain the angle C A B 30° 23′. We find by trigonometry A C to be 288 links. The sum of the angles E A F and C A B, taken from 180°, gives the angle E A C 98° 24′. Lastly, subtract the angle H D E from 180, and you get the angle E D C 91° 20′.

Then, by the preceding problem, in the triangle A B C we obtain from the two sides A B, B C, and the included angle A B C, the double area - - - 28256 8

In the triangle E A C, from the sides
A C, A E, and angle E A C - 4625146

In the triangle E D C from the sides
D E, D C, and angle E D C - 5823047

2)13273851

Area 66.36925

Answer, 66 acres, 1 rood, 19 perches.

If the angles had been measured with a mariner's compass, they must have been arranged in a traverse table similar to plane sailing in navigation, and the content found by the method shewn in my *Graphical Essays*.

Problem vi.

To find the altitude and height of fire-balls, and other meteors, in the atmoſphere.

Though the extreme velocity and tranſient nature of fiery meteors in the atmoſphere, in a great meaſure prevents the making of ſuch obſervations as might tend to aſcertain their diſtance, yet they form a ſubject of inquiry ſo curious and intereſting, as renders ſuch as can be made of great value. An obſerver, who preceives an appearance of this kind, ought carefully to note the buildings, trees, ſtars, &c. near which it paſſes; and, as ſoon afterwards as convenient, take their altitude and bearings. If two ſuch obſervations be taken by perſons at different places, ſufficiently diſtant from each other, the diſtance on the earth may be conſidered as the baſe, and from this and the two obſerved angles the height of the meteor may be found by problem ii.

By obſervations of this kind it has been found, that the larger fire-balls are elevated about 60 miles above the earth's ſurface, and that ſome of them are near five miles in diameter.

PROBLEM VII.

To find the height of a cloud, by obſervation of a flaſh of lightning.

If the altitude of that part of a cloud, from which a flaſh of lightning has iſſued, be immediately taken with the quadrant, and the number of ſeconds of time elapſed between the inſtant of the flaſh, and the firſt arrival of the thunder, be reckoned, theſe data will be ſufficient to determine the height of the thunder-cloud. For ſound is admitted to paſs through 1142 feet in a ſecond; but light has ſuch an extreme velocity, that it paſſes through thirty-five thouſand miles in a ſecond, and may therefore be reckoned inſtantaneous in all obſervations upon the earth. Hence it follows, that the number of ſeconds obſerved, multiplied by 1142, will give the diſtance of the cloud in feet; and

As radius
Is to the ſine of the obſerved angle;
So is the diſtance of the cloud
To it's height.

Example. Suppoſe the angle of elevation C A B, from which a flaſh of lightning iſſued, was 53 8′, and that between the flaſh and the report of the thunder 5 ſeconds were counted; then

1142 feet multipled by 5 gives 5710 feet for the diſtance of the cloud. Fig. 6, plate XV.

And as radius or ſine of 90°	10.0000000
Is to the ſine of the obſerved angle 53° 8′ - -	9.9031084
So is the diſtance of the cloud 5710	3.7566361
To it's height 4568 feet -	3.6597445

Or by conſtruction. From a point in any right line, draw another right line, forming the obſerved angle. Set off on this left line, from the angular point, the diſtance of the cloud, taken from a ſcale of equal parts. From the extreme of the laſt-mentioned line let fall a perpendicular on the other line; and this perpendicular will be the height required.

If the flaſh of lightning ſtrike directly down, the height of the cloud will alſo be the length of the flaſh. But this is not often the caſe.

Problem VIII.

To determine the height of a cloud by obſervations on it's altitude and velocity.

When the ſky abounds with detached clouds, moving with conſiderable velocity, it is eaſy to determine the degree of ſwiftneſs, by obſerving the progreſs of their ſhadows which paſs along the ground. For this purpofe nothing more is neceffary, than to note the inftants of time when one of thefe fhadows paffes over two objects, fuch as hedges, trees, &c. lying in it's direction; and to meafure the interval paffed over during the intermediate time. When this velocity is thus found, place the plane of the quadrant in the direction of the wind, and fetting the fights to a confiderable altitude, to be written down, take notice of fome remarkable edge of a cloud, which paffes acrofs the wire in the aperture of the fartheft fight, giving notice at the fame inftant to an affiftant to note the time. Then move the quadrant on it's axis twenty or thirty degrees, and give the like notice to the affiftant when the fame part of the cloud paffes the wire; write down this laft altitude. The perpendicular height of the cloud will be found by the following proportions.

As the number of feconds obferved when the fhadow of the former cloud was feen on the ground

Is to the number or feconds elapfed between the two obfervations with the quadrant;

So is the diftance meafured on the ground

To the diftance paffed through by the cloud (whofe altitude was taken) during the time of obfervation.

500

Then,

As the ſine of the difference between the two altitudes
Is to the ſine of the leſs altitude;
So is the diſtance paſſed over by the cloud,
To it's diſtance from the obſerver, when the greater altitude was taken.

And laſtly,

As radius
Is to the ſine of the greater altitude;
So is the diſtance laſt found
To the perpendicular height of the cloud.

Example. The ſhadow of a cloud was obſerved to paſs over 1230 yards in 50 ſeconds; it's altitude at that inſtant was 41 degrees; three minutes after, it's altitude was 11 degrees 37 minutes: to find it's height.

Now the ſpaces deſcribed by bodies moving with equal velocity, are as the times of deſcription; therefore, by the firſt part of the rule, as 50 ſec, to 180 ſec. ſo is 1230 yds. to 4428 yds. the diſtance paſſed over by the ſhadow during the obſervation.

But the progreſſive motion of the ſhadow from B to C, fig. 7, plate XV, during the elapſed time between the obſervations, is the ſame as if the obſerver had moved in the ſame time from B towards A; or the effect would be exactly the ſame if an obſerver at A took the leſs altitude, while another at B took the greater altitude at the ſame inſtant. Hence the ſecond part of the rule is evident; for A D E is the complement of the leſs angle, and B D E that of the greater. The difference of theſe complements is equal to the angle A D B; but the difference of the complements muſt be equal to the difference of the altitudes; therefore, by the ſecond part of the rule,

As the ſine A D B of the difference between the two altitudes 29° 38′	9.6907721
Is to the ſine of the leſs altitude D A B 11° 37′ - -	9.3039794
So is the diſtance A B paſſed over by the cloud 4428 yards -	3.6462076
	12.9501870
	9.6907721
To it's diſtance at the time of the greater altitude B D 1817.2 yds.	3.2594042

Laſtly, by the laſt part of the rule, ſee likewiſe the rule to problem viii.

As radius ſine of 90 - -	10.
Is to ſine of greater altitude 41	9.8169429
So is the diſtance B D 1817.2 -	3.2594049
To the perpendicular height D E 1192.2 yards - -	3.0763478

Principles and Problems preparatory to the Application of the Instruments to Practical Astronomy.

By practical aſtronomy is underſtood the knowledge of obſerving the celeſtial bodies, with reſpect to their poſition, and time of the year; and of deducing from theſe obſervations certain concluſions, uſeful in calculating the time when any propoſed poſition of thoſe bodies ſhall happen.

Of Terrestrial Latitude.

The latitude of any place is equal to the elevation of the pole of the equator above that place.

The diſtance between the zenith and the horizon, and that between the pole, is equal, for each of them are 90 degrees. If, therefore we take away the diſtance of the zenith from the pole, which is common to both, the remainder, that is, the elevation of the pole, or latitude of the place, is equal to the diſtance from the zenith to the equator.

The diſtance from the zenith to the pole, is equal to the complement of the latitude to 90 degrees.

The inclination of the equator to the horizon, is alſo equal to the complement of the latitude to 90 degrees.*

All thoſe ſtars that are not further from the pole than the latitude, are called *circumpolar* ſtars.

If the greateſt and leaſt altitudes of a circumpolar ſtar be determined by obſervation, half the ſum gives you the *latitude* of the place.

The complement of the meridian altitude of a ſtar is it's *zenith diſtance ;* and this is called

* In fig. 5, plate III, P repreſents the pole, E Q the equator, H O the horizon, P H the elevation of the pole, Z the zenith. H Z O, or the viſible part of the heavens, contains twice 90, or 180 degrees; it being 90 degrees from Z to H, and 90 degrees from Z to O: but it is alſo 90 from the pole P, to E the equator. If you take away PE, there remain 90 degrees for the other two arcs. In other words, the elevation of the pole and the elevation of the equator are together equal to 90 degrees; *i. e.* in technical terms, the elevation of the pole is the complement of the elevation of the equator to 90 degrees. Hence one being known and ſubtracted from 90, gives the other.

Hence alſo it is clear, that the elevation of the equator is equal to the diſtance of the pole from the zenith, both being equal to the diſtance of the pole from 90 degrees.

Hence alſo the diſtance of the equator from the zenith is equal to the elevation of the pole, or latitude of the place; for H Z is equal to 90, and P E is equal to 90: take away P Z, common to both, and the remainders, P H, Z E, muſt be equal.

north or ſouth, according as the ſtar is north or ſouth at the time of obſervation.

The *latitude* of a place is equal to a ſtar's meridian zenith diſtance added to the declination, if the ſtar paſſes between the zenith and the equator. In all other caſes, the *latitude* is the difference between the meridian zenith diſtance and the declination of the ſtar.

The greateſt declination of the ſun, is equal to the inclination of the ecliptic to the equator.

The inclination of the equator to the ecliptic, is equal to half the difference between the ſun's meridian altitudes on the longeſt and ſhorteſt days.

The latitude of the place, and the zenith diſtance of a ſtar, being given, to find the declination of the ſtar.

1. When the latitude of the place and zenith diſtance are of different kinds, that is, one north, and the other ſouth, their *difference* is the *declination;* and it is of the ſame name with the latitude, when that is the greater of the two; otherwiſe it is of the contrary kind.

2. When the latitude and zenith diſtance are of the ſame kind, that is, both north, or both ſouth, their *ſum* is the declination, and it is of the ſame kind with the latitude.

Of Celestial Longitude, Latitude, &c.

It has been already obferved, that in order to meafure and eftimate the motion of the fun and ftars, it was neceffary to fix on fome point in the heavens to which their motions might be referred. The *vernal equinoctial point* is that point from which aftronomers reckon what is called *longitude* in the celeftial fphere. The ecliptic is divided into twelve figns, of 30 degrees each, with whofe names and characters you are acquainted. Aftronomers begin at the firft point of Aries, and reckon from weft to eaft.

Celeftial longitude is therefore the number of degrees on the ecliptic contained between the firft point of Aries and any celeftial object, or between the firft point of Aries and a circle paffing through the object perpendicular to the ecliptic. Thus if ♈ c, fig. 8, plate XV, reprefents the ecliptic, and ♈ the firft point of Aries, and any ftar be at S on the ecliptic, or at s on a circle p s S, perpendicular to the ecliptic then will the arch ♈ S be the longitude of the ftars S, s.

The *latitude of a celeftial object* is it's diftance from the ecliptic, reckoned on a circle perpendicular thereto. Thus a ftar at s, fig. 8, plate XV, will have for latitude the arc S s;

but placed at S on the ecliptic, will have no latitude.

As the diurnal motion is in the direction of the equator, aſtronomers, to facilitate both obſervation and calculation, found it neceſſary to determine the ſituation of celeſtial bodies with reſpect to this circle, which is effected by determining their right aſcenſion and declination. *Right aſcenſion* and *declination* are, with reſpect to the *equator*, what *longitude* and *latitude* are with reſpect to the *ecliptic*. Thus if ♈ Q repreſent the equator, and ♈ the firſt point of Aries, then will ♈ E be the right aſcenſion of a ſtar ſituated at E on the equator, or at e in a circle e E perpendicular thereto: the ſtar at E will have no declination, but that at e is meaſured by the arch e E.

General Observations.

To fix your attention, with greater certainty, to the objects of reſearch, it may be proper to obſerve, that as *practical aſtronomy* conſiſts in determining the poſition of celeſtial objects for a given inſtant, it may be reduced to three things.

1. *The knowledge of the obliquity of the ecliptic.*

2. *The meaſure of time.*

3. *The right aſcenſions and declinations of the ſtars, &c.*

Of the Obliquity of the Ecliptic.

The obliquity of the ecliptic is a very important element of aſtronomy, becauſe it enters into the calculation of all ſpheric triangles where the ecliptic and equator are concerned.

The obliquity of the ecliptic being equal to the ſun's greateſt declination, *i. e.* when in the tropics, the obliquity may be aſcertained by obſerving the meridian height of the ſun's center on one of the ſolſtitial days; and this quantity taken from the height of the equator, at the place of obſervation, gives the declination of the tropic. Or, more accurately, obſerve the ſun's meridian altitude in each tropic: this will give their diſtance, half of which is the diſtance of each tropic from the equator, that is, the obliquity of the ecliptic. From good obſervations, made in 1772, this obliquity was found to be 23° 28′.

Of the Measure of Time.

All aſtronomical obſervations depend on, or have a reference to time. To meaſure this with accuracy, is one of the primary objects of an aſtronomer.

As the diurnal revolution of the earth is found to be uniform, they have taken this for the meaſure of time, comparing it with the ſun. Aſtronomers conſider *noon* as the beginning of the diurnal revolution ; or, in other words, an *aſtronomical day* commences at the inſtant the center of the ſun is the plane of our meridian, and finiſhes when it has returned thereto, after one entire revolution.

The *aſtronomical* day begins therefore twelve hours later than the *civil* day of the ſame denomination, and is counted up to twenty-four hours, or the ſucceeding noon, when the next day begins. Thus the day of the month, and the hour of the day, are the ſame in this method as in the civil account at noon, and from noon till midnight : but from midnight till noon, they differ ; for in the civil account a freſh day begins at midnight and the hours alſo begin again, but in the aſtronomical method the day is ſtill continued beyond the midnight. Hence five o'clock in the morning of April the 10th, is called by aſtronomers April 9, 17 hours.

As the earth revolves uniformly on it's axis, if it had *no real annual* motion, and conſequently the ſun *no apparent annual* motion, or if this motion was uniform, the days would be all neceſſarily of one length, and that would be about 23 hours 56 minutes, for in that time a diurnal revolution of the earth is completed, as appears by an eaſy obſervation; for any fixed ſtar that is on the meridian at a given hour of the night, will, after 23 hours 56 minutes, be on the meridian again the night following. This interval of time is called a ſiderial day.

But accurate obſervations have ſhewn, that the *ſolar days* are not equal to each other, and that the time which elapſes between the ſun's being on the meridian of any place, and it's return thereto again, is conſiderably longer ſometimes than at others.

Hence aſtronomers have been obliged to diſtinguiſh two ſorts of time; one they call *apparent*, the other *mean* time.

Apparent time (called by foreign writers *true time*) is that determined immediately from the ſun, by obſerving when his center tranſits the meridian, which is at the inſtant of apparent noon, when a new aſtronomical day commences.

Mean time is that which would be obſerved every day, if the apparent diurnal motion of the ſun was regular; or that ſhewn by good clocks or watches, which go uniformly. The mean day of 24 hours, pointed out by theſe, muſt neceſſarily be always of the ſame length.

The inequality in the length of the natural

tural days is termed the *equation of time.* Now as aſtronomical tables can only be calculated to mean or uniform time, the proper reſults from an obſervation cannot be obtained, till the obſerved or apparent time is reduced to mean time; for which purpoſe proper tables are calculated, called tables of the *equation of time.*

Theſe are inſerted on the ſecond page of every month in the Nautical Almanac, for the noon of each day at Greenwich. It is marked *ſubtractive*, when the ſun comes to the meridian ſooner, and *additive*, when it comes to the meridian later than the time of mean noon; that is, the quantity given by the table is to be ſubtracted from apparent, in order to obtain mean time, in the firſt caſe, and added to it in the ſecond.

OF CORRESPONDING OR EQUAL ALTITUDES.

At equal diſtances from the meridian, a ſtar has equal altitudes. If, therefore, equal altitudes of an heavenly body be taken on different ſides of the meridian, the middle point of time between the obſervations will give the time when the body is upon the meridian, if it has not changed it's declination. By this means the *time* when any body comes to the meridian may be aſcertained; and when applied to the ſun, or a fixed ſtar, the rate at which a clock (adjuſted to the mean ſolar or ſiderial time) gains or loſes may be determined with accuracy.

The method of aſcertaining time by equal altitudes is univerſally uſed by practical aſtronomers, becauſe it depends neither on an accurate knowledge of the latitude, nor on that of the declination; for theſe elements are only neceſſary in taking out the equation of declination, and any probable error therein will not ſenſibly effect that equation; neither does it depend on the exact quantity of the altitude, provided only it be the ſame in both obſervations.

Of the Right Ascension and Declination of the Stars.

The *declination* of ſtars, &c. is eaſily found by obſerving their *meridian altitudes;* and their *right aſcenſion* is alſo eaſily attained by knowing how *to meaſure time.*

For as all ſtars in the ſame circle of declination have the ſame right aſcenſion, it follows, 1ſt, That all ſtars paſſing at the ſame time through the ſame meridian, have then the ſame right aſcenſion. 2dly, The right aſcenſion of ſtars paſſing the meridian at different times, differ in proportion to the intervals of the times of their paſſage.

Example. The ſtars make a revolution in 23 56′ 4″ mean time. If, therefore, by a clock regulated to mean time, and an inſtrument fixed in the plane of the meridian, or by correſponding altitudes, or otherwiſe, a ſtar be obſerved to paſs the meridian one hour after the other; ſay as 23^h 56′ 4″, the time of one revolution, is to 360 of the equator paſſed over the meridian in the ſame time, ſo is one hour, the difference between the tranſits of the ſtars, to 15° 2′ 28″, difference between their right aſcenſions; then the right aſcenſion of one being known, the other is alſo known.

Whence it follows, that to determine the right aſcenſion of any ſtar, or even of all the ſtars, it is ſufficient to know the right aſcenſion of one ſtar only, and to have a clock which ſhews an equal interval of time for the diurnal revolution of the ſeveral different fixed ſtars.

Problem IX.

To reduce degrees of the equator into time, and time into degrees of the equator.

1. To reduce degrees into time, multiply by 4; obſerving that minutes, when multiplied by 4, produce ſeconds, and degrees produce minutes.

Reduce 23° 56′ into time

$$\begin{array}{r} 23°\ 56' \\ 4 \\ \hline 1\ \ 33'\ 44'' \end{array}$$

Reduce 69° 20′ 45″ into time.

$$\begin{array}{r} 4 \\ \hline 4^h\ 37'\ 23''\ 00^{\text{thirds.}} \end{array}$$

2. To reduce time into degrees, multiply by 10 in a similar manner, and increase the produce one-half, or divide the time by 4.

Reduce 1ʰ 33′ 44″ into degrees.

$$\begin{array}{lrrr} & 1^h & 33' & 44'' \\ & & & 10 \\ \hline & 15 & 37 & 20 \\ \text{Half} & 7 & 48 & 40 \\ \hline \text{Degrees} & 23 & 26 & 0 \end{array}$$

Reduce $4^h\ 37'\ 23''$ to degrees.

		10
	46	13 50
Half	23	6 55
Degrees	69	20 45

Of Reduction from one Meridian to another.

As all the heavenly bodies rife, culminate, and fet, fooner to thofe who are towards the eaft, and later to thofe who are towards the weft, and as all tables and calculations in England for aftronomy and navigation are adapted to the meridian of Greenwich, it is neceffary for thofe who may be under any other meridian, to be able to find the time at Greenwich correfponding to that pointed out by their own clocks and watches.

Without this reduction no calculations can be made from fuch tables, or from the various articles contained in the Nautical Almanac, relating to the longitude, right afcenfion and declination of the fun, the equation of time, moon's motion, &c. fo as to adjuft them to any other meridian than that for which they were made.

To find the time at Greenwich corresponding with any given time under another meridian.

1. Find the difference of longitude between the two meridians, or how much the given place or meridian is to the east or west of Greenwich, and reduce this difference to time, by the foregoing rule.

2. If the given place be east of Greenwich, subtract the difference of meridians from your time; if it be west, add the difference to your time. The result will give the time it then is at Greenwich.

N. B. The time being given at Greenwich, the corresponding time under any other meridian is found by reversing this rule.

Example. What is the time at Greenwich, when it is 8^{h} 17′ 19″ at Jerusalem, 35° 30′ east of Greenwich, or in time 2^{h} 21′ 20″? *Answer*, 5^{h} 55′ 59″

Required the time at Greenwich, when it is 23^{h} 32′ 17″ at Boston, on the 12th of June; Boston being 4^{h} 42′ 29″ west. *Ans.* 28^{h} 14′ 46″, or 4^{h} 14′ 46″ P. M. on the 13th of June.

What is the time at Jerusalem, when it is 21^{h} 49′ 17″, on the 9th of September, at Greenwich? *Answer*, 24^{h} 10′ 37″, or 0^{h} 10′ 37″ on the 10th of September.

Again, required the time at Boston, when it is 3h 37′ 0″ on the 1ſt of May at Greenwich? *Anſwer*, 22 54′ 31″ of the laſt day of the preceding month, or 10 54′ 31″ of civil time, on the morning of the 1ſt of May.

N. B. To know the time at Paris, Genoa, &c. when it is any given time where you are, take the difference between your meridian and that of Paris, &c. and then proceed as in the foregoing rule.

To find any of the motions of the ſun or planets, the equation of time, right aſcenſion, declination, ſemi-diameter, and parallax of the moon; alſo the moon's diſtance from the ſtars, for any given time, under any other meridian.

Rule. 1ſt, Find by the preceding problem the time at Greenwich which correſponds to the time under the given meridian. 2dly, Take the daily, the half-daily, &c. (according to the interval for which you are to calculate) variation from the Nautical Ephemeris, and by even proportions find the time that correſponds to the interval between this time, and that given in the Ephemeris. 3dly, Add or ſubtract this variation according as the motion is increaſing or decreaſing.

Example. What is the ſun's declination at Greenwich, March 27, 1790, at 9h. The reaſon why Greenwich is mentioned, and not any other place, is, becauſe the time, at whatever place you may want the declination, is ſuppoſed to be already reduced to that of Greenwich, as the firſt ſtep to be attended to in all ſuch problems.

March 28. Declination at noon	3°	10′	47″	N.
March 27. Ditto ditto	2	47	23	
Variation of declination in 24 hours - -	0	23	24	
Variation in 9 hours, per table	0	8	46	
Which, added to declination,	2	47	23	
Gives the required declination	2	56	9	

Example. Required the ſun's declination, 1790, Auguſt 24, 2° 57′ at Greenwich?

Auguſt 24. Declination at noon	10	58	59
25. Ditto ditto	10	38	16
Variation in 24 hours -	0	20	43
Variarion in 2 hours 57 min.	0	2	36
Which ſubtracted from -	10	58	59
Gives the declination required	10	56	23

PROBLEM X.

To find at what time, by a clock keeping mean time, any fixed ſtar will be on the meridian on any given day.

The right aſcenſion of the ſtars being reckoned on the equator, they paſs the meridian ſucceſſively in times proportional to their reſpective diſtances therefrom. The diſtance of a ſtar from the meridian, is therefore nothing more than it's difference, in right aſcenſion, from the ſun reduced to time; from whence it is plain, that to find the time when any ſtar comes to the meridian, you muſt ſubtract the right aſcenſion of the ſun at noon from that of the ſtar; the difference is the time required.

This ſimple calculation would be ſufficient in general for finding the time when a ſtar tranſits the meridian, if it always preſerved the ſame difference in right aſcenſion from the ſun: but the ſun, by it's diurnal acceleration, approaches the ſtar inſenſibly; and will conſeqently paſs the meridian ſooner, by a quantity proportional to this acceleration, and it's diſtance from the ſun. It is therefore neceſſary to ſubtract from the quantity firſt found, another ſmall quantity, that may be aſcertained. Hence the following rule.

Rule.

Take the difference between the ſun's and planet's motion, in right aſcenſion, in 24 hours, if the planet is progreſſive, or their ſum if retrograde; then ſay,

As 24 hours, diminiſhed by this ſum, or difference, when the planet's motion is greater than the ſun's, or increaſed by it, when the ſun's motion is the greater,

: Is to 24 hours,

: : So is the difference between the ſun's * and planet's right aſcenſion at noon, to the time required.

For a ſtar.

Take the increaſe of the ſun's right aſcenſion in 24 hours, and add it to 24 hours; then ſay,

As this ſum

: Is to 24 hours,

: : So is the difference between the ſun's * and ſtar's right aſcenſion

: To the time required.

* In the latter part of both theſe rules, the ſun's right aſcenſion is to be taken from the planet's or ſtar's right aſcenſion; and if their right aſcenſions ſhould be leſs than the ſun's, they muſt be increaſed by 24 hours, before you ſubtract.

Examples.

On July 1ſt, 1767, the ſun's right aſcenſion, when on the meridian of Greenwich, was 6^h $40' 25''$; and on July 2d, it was 6 $44' 33''$: alſo the moon's right aſcenſion was $159° 2'$; and on July 2d, it was $169° 39'$. Required the time of the moon's paſſage over the meridian?

Sun's ☉'s R. A. July 1,	6^h	$40'$	$25''$
— — — 2,	6	44	33
Daily increaſe	0	4	8

Moon's ☽'s R. A.	$159°$ $2'$	-	10^h	$36'$	$8''$
— —	169 39	-	11	18	36
Daily increaſe			0	42	28

Moon's motion in 24 hours	$42'$	$28''$
Sun's - -	4	8
Difference	38	20

Sun's R. A. at noon	6^h	$40'$	$25''$
Moon's R. A. at noon	10	36	8
Difference	3	55	43

As $24^h\ 38'\ 20'' = 23^h\ 21'\ 40'' : 24 :: 3^h\ 55'\ 43''$

60	60
1401	235
60	60
84100	14143
	24
	56572
	28286

84100) 339432 ($4^h\ 2'\ 9''$
336400

3032
60

84100) 181920 (2
168200

13720
60

84100) 823200 (9
7569

66300

Anſwer $4^h\ 2'\ 9''$, the time required.

At what time will the ſtar *Arcturus* come to the meridian of Greenwich on the firſt of September, 1787?

Sun's R.A. 1 Sept.	$10^h\,41'\,59''$	Star's R.A.	$14^h\,6'\,0''$
- 2	10 45 37	-	10 41 59
Increaſe in 24^h	0 3 38	Diff.	3 24 1

As $24^h\,3'\,38''$: 24^h : : $3^h\,24'\,1''$: $3^h\,23'\,31''$ the time required.

Problem XI.

To find the altitude of the ſun, or any other celeſtial body.

This conſiſts in the ſimple application of the quadrant to a celeſtial body, in the ſame manner as I have already ſhewn with reſpect to terreſtrial objects.

The quadrant being adjuſted as it ſhould be, in all caſes previous to it's uſe, the celeſtial body muſt be viewed through the ſights, and the plumb-line will ſhew it's altitude on the graduated limb of the inſtrument.

If the obſervation be made on the ſun, the dark glaſs muſt be uſed to defend the eye, or the luminous ſpot formed by the ſmall hole muſt be made to fall on the center of the croſs immediately beneath the eye-hole.

The ſun having no viſible point to mark out it's center, you muſt take the altitude either of the upper or lower limb. If the lower limb be obſerved, you muſt add the ſun's ſemi-diameter thereto, in order to find the altitude of the ſun's center. If the altitude of the upper limb be obſerved, the ſemi-diameter muſt be ſubtracted. The mean ſemi-diameter of the ſun is 16 minutes, which for common obſervation may be taken as a conſtant quantity, for the greateſt deviations from this quantity ſcarcely exceed a quarter of a minute. When greater accuracy is aimed at, the ſemi-diameter may be taken from the Nautical Almanac. The obſerved altitude of the ſun's lower limb being 18° 41′, add thereto 16 min. for the ſun's ſemi-diameter, and you obtain 18° 57′, the central altitude.

The apparent altitudes of all the heavenly bodies are increaſed by *refraction*, except when they are ſituated in the zenith. An obſerved angle of a ſtar, or any other object in the heavens, muſt be diminiſhed a ſmall quantity, to be taken from the *table of refractions*.

Where greater exactneſs is required, a ſmall quantity is to be added for the error occaſioned by parallax, or the difference between the altitude of an object as ſeen from the center and the ſurface of the earth. That from the center is the true altitude, and the greateſt, except at the zenith, where parallax vaniſhes; conſequently the apparent altitude of the ſun is to be augmented by a ſmall quantity taken from the *table of the ſun's parallax*.

June 6, 1788, the apparent altitude of the ſun's lower limb was obſerved to be 62° 19′: required the true altitude of the ſun's center, as ſeen from the center of the earth.

Obſerved altitude - -	62°	19′	
Semi-diameter - -		16	
	62	35	
Subtract for refraction -			30
	62	34	30
Add for parallax - -			4
True central altitude -	62	44	26

If it is a fixed ſtar that has been obſerved, there is no correction for ſemi-diameter or parallax; you have only to ſubtract for refraction, in order to obtain the true altitude.

Thus let the obſerved altitude of Arcturus be - -	38°	40′	
Subtract for refraction -		1	10
True altitude - -	38	38	50

Problem xii.

To find the latitude of the place of obſervation.

When the ſun, or a ſtar, is nearly on the meridian, or a few minutes before twelve at noon, take it's altitude, and repeat this obſervation, at ſhort intervals of time, till it is found neither to increaſe nor diminiſh. This laſt, or greateſt altitude, is the meridian altitude. When the ſun is the object, you muſt obtain the true central altitude, by correcting for ſemi-diameter and refraction, as ſhewn in the preceding problem.

Having obtained the meridian altitude, the firſt object for conſideration is, whether the latitude be north or ſouth, and whether the declination of the object be north or ſouth. If the latitude and declination be both north, or both ſouth, they are ſaid to be of the ſame name; but if one be north, and the other ſouth, they are ſaid to be of different denominations. This being determined, to find the latitude,

1. Take the given altitude from 90°, to find the zenith diſtance. 2dly, If the zenith diſtance and declination be of one name, ſubtract one from the other, and the difference is the latitude; but if they have contrary names, their ſum gives the latitude.

The latitude is always of the ſame name with the declination, unleſs when the declination has been ſubtracted from the zenith diſtance.

Example.

Aug. 17, 1776, Cambridge. The apparent altitude of the ſun's lower limb - -	53° 46′ 8″
Sun's ſemi-diameter - -	16
Apparent altitude of the ſun's centre - - -	54 2 8
Subtract for refraction -	41
Real altitude of the ſun's centre	54 1 17
This ſum, taken from 90°, gives the zenith diſtance of the ſun's center - -	35 58 43
Add for the ſun's declination	16 13 57
The ſum is the latitude of Cambridge - -	52 12 40

N. B. The ſun's declination, as found in the tables, is to be reduced by the rules given † p. 517, to the meridian of obſervation.

Nov. 6, 1792. Long. 158° W. the meridian altitude of the ſun's lower limb was obſerved to be 87° 37′ N. required the latitude?

† Refer to the pages at bottom.

Obſerved altitude	-	87° 37	
Sun's ſemi-diameter	-	16	
Altitude of the ſun's center	-	87 53	
This, from 90, give the zenith diſtance	- -	2 7	
Declination reduced	-	16 25	S.
Latitude required	- -	18 32	S.

Dec. 1, 1793. The obſerved meridian altitude of Sirius was 59° 50′ S. required the latitude?

Obſerved altitude	-	59°	50′	S.
Zenith diſtance	- -	30	10	N.
Declination of Sirius	-	16	27	S.
Latitude required	- -	13	43	N.

Problem XIII.

To find the time by equal or correſponding altitudes.

This problem is of extenſive uſe, for the baſis of all aſtronomical obſervation is the determination of the exact time of any appearance in the heavens; which cannot be attained, unleſs you are aſſured of the going of your watch or clock. I have before ſhewn you, that a mean ſolar day is always conſidered as of the ſame determinate length; but the length of an apparent day is variable, being ſometimes longer, ſometimes ſhorter, than a mean day. The inſtant, therefore, of apparent noon will ſometimes follow, at others precede, that of mean noon. The interval between apparent and mean time, is called the equation of time.

To find, then, the time of apparent noon, obſerve the ſun's altitude in the morning, and alſo the time by a clock or watch. Leave the quadrant in the ſame ſituation, taking care that it's poſition be not altered by any accident; and in the afternoon direct it to the ſun, by moving the index of the horizontal circle only, and obſerve the time when the ſun's altitude correſponds with that to which the quadrant was ſet in the morning. Add the times of obſervation together; the middle inſtant between theſe times of obſervation is that of apparent noon: this being corrected, by adding or ſubtracting the equation of time, g ves the time of true noon. If it be preciſely XII, the clock is right; but if it differ, the clock is faſter or ſlower, by the quantity of the difference greater or leſs than XII.

Thus ſuppoſe the time in the morning to be - -	21° 35′ 8″
That in the afternoon -	2 55 43
	24 30 51
The time of moon by watch	12 15 51
Equation of time - -	13 29
Mean noon by watch -	12 2 22

The watch is therefore 2 min. 22 ſec. too faſt.

To be more particular and accurate. In our latitude, the altitudes ſhould be taken when the ſun is at leaſt two hours diſtant from the meridian. The beſt time is when the ſun is on or near the prime vertical, or eaſt and weſt point of the compaſs ; becauſe his motion perpendicular to the horizon is greateſt at that time.

About this time, in the *forenoon*, take ſeveral altitudes of the ſun, writing down the degrees and minutes ſhewn on the arch, and alſo the exact time ſhewn by the clock at each obſervation : the obſervations to be written one below the other, in the order, they were made ; the time of each obſervation being previouſly increaſed by 12 hours.

In the *afternoon* ſet the in degree and minute as the laſt obſ exactly the time ſhewn by the clock ſun is come down to the ſame altitu write down the time oppoſite to the laſt mo ing altitude; proceed in the ſame manner to note the time of all the altitudes correſponding to thoſe taken in the morning, writing down each of them oppoſite to that morning one with which it correſponds.

Half the ſum of any pair of correſponding altitudes, will be the time of noon by the watch uncorrected. Find the mean of all the times of noon thus deduced from each correſponding pair of obſervations; which correct for the change in the ſun's declination, and you obtain the exact time ſhewn by the clock at ſolar noon. This, corrected by the equation of time, gives the time of mean noon; and the watch will be too faſt or too ſlow, according as the time of noon thus found is more or leſs than 12 hours.

Example 1. Equal altitudes taken, June 1782.

Morning.	Afternoon.
$20^h\ 55'\ 46''$	$3^h\ 8'\ 44''$
20 57 41	3 6 48
20 59 27	3 4 58

		2d pair	20h	57m	41s	3d pair	20h	59m	27	
	14		3	6	48		3	4	58	
4	30		24	4	29		24	4	25	
2	15		12	2	14½		12	2	12½	

the feconds differ, add them together, and divide the Sum by 3 (the number of pairs) which gives you a mean 15

14½

12½

3) 42

14

Therefore the mean of the obferved time is - -	12h	2′	14″	
Equation for 6 hours difference in declination - -				8
Time per watch of apparent noon - .	12	2	14	8
Equation of time -		1	55	1
Time per watch of mean noon	12	0	19	7

The watch is 19 fec. 7 thirds too faft for mean time.

Example 2. January 2

Morning.	Aft
21h 35′ 8	2h 5
21 36 8	2 54 42
21 38 9	2 52 41 2
21 39 12½	2 51 38

	1st pr.	2d	3d	4th
	21h 35m 8s	21h 36m 8s	21h 38m 9s	21h 39m 12s 5t
	2 55 43	2 54 12	2 5‸ 41 2	2 51 38
Sum	24 30 51	24 30 50	24 30 50 2	24 30 50 5
½ sum	12 15 25 5	12 15 25	12 15 25 1	12 15 25 2

The difference here is only among the thirds, which added together are 8‴, divided by 4 we have 2. Therefore

The mean of the observed time is	12h	15′	25″	2‴
Equation for declination -			20	2
Time of apparent noon by watch	12	15	5	0
Equation of time -	0	13	29	8
Time by watch of mean moon	12	1	35	2
Watch too fast for mean time		1	35	2

Problem xiv.

To find the error of a clock or watch, by correspon-ding or equal altitudes of a fixed star.

Rule 1.

Add half the elapsed time between the observations, to the time when the first altitude

i you have the time of the ſtar's
the meridian per watch.

Rule. 2.

ptract the ſun's right aſcenſion from the ſtar's, increaſed by 24 hours, if neceſſary. Take the increaſe of the ſun's right aſcenſion in 24 hours, and add it to 24 hours; then ſay,

As this ſum
: Is to 24 hours,
: : So is the difference between the ſun and ſtar's right aſcenſion
: To the true time of the ſtar's tranſit.

If the watch be regulated to ſolar time, the difference between the true time of the ſtar's tranſit and the time ſhewn by the watch, will be the error.

If your meridian be different from that of Greenwich, ſay,

As 24 hours
: Are to the daily difference of the ſun's right aſcenſion;
: So is the longitude, in time,
: To a proportional part, which muſt be added to the true time of the ſtar's tranſit, if the longitude be eaſt, but ſubtracted if weſt.

If the watch be regulated to mean ſolar time, that is, if it divides the time equally, apply the equation of time as directed in page II. of the Nautical Almanac, to the

true apparent time of the ftar[illegible]
you fubtract.

Examples.

On the fixth of November, 1787, at 11h 10′ 9″ P.M. and at 16h 4′ 15″ folar time, the ftar Aldebaran had equal altitudes at Greenwich. Was the watch too faft or too flow?

	16h	4′	15″
	11	10	9
2)	4	54	6
Half elapfed time -	2	27	3
Time 1ft altitude	11	10	9
Star's tranfit per watch	13	37	12

Star's R. A.	4h	23′	50″
	24		
	28	23	50
Sun's R. A	14	46	15
Diff.	13	37	35

Sun's R. A. Nov. 6	14h	46′	15″
— — 7	14	50	15
Increafe in 24 hours	0	4	0

13^h 37′ 35″: 13^h 35′ 19″ true time.

…er watch 13 37 12

20

Watch too fast 0 1 53

…the… July 13, 1792, in longitude 23° 26′ E. the following equal altitudes of Altair were observed. Required the errors of the watch?

	Time per watch.		Altitude.		Time per watch.
	8^h 17′ 0″	-	27 23′	-	14^h 35′ 57″
	0 19 16	-	27 40	-	0 33 42
	0 20 12	-	27 55	-	0 32 44
	0 21 54	-	28 12	-	0 31 5
	0 23 16	-	28 30	-	0 29 41
	8 25 55	-	28 52	-	14 27 1
Sum	50 7 33		-	-	87 10 10
Mean	8 21 15 5		-	-	14 31 41

Mean time of 1st observation 8^h 21′ 15″ 5‴
Mean time of 2d observation 14 31 41 6

2) 6 10 26 1 Diff.

Half elapsed time 3 5 13

Star's R. A. 19^h 40′ 40″
Sun's R. A. 8 13 41

Difference 11 26 59

Sun's R. A. at noon,
Ditto - 24

Increase it 24 hours

Tru

$24^h\ 3'\ 58'' : 24 :: 11^h\ 26'\ 59'' : 11^h\ 25$
$24^h : 3'\ 58'' :: 1^h\ 33'\ 44''$ pro part. 0 0

True time of star's transit corrected for longitude -	11	25	21
Time per watch -	11	26	28
Watch too fast for apparent time	0	1	7

Secondly, Suppose the watch had been regulated to mean solar time. Then,

True apparent time of star's transit, as above -	11^h	$25'$	$21''$
Equation of time -	0	6	3
True mean solar time -	11	31	24
Time per watch - -	11	26	28
Watch too slow for mean solar time	0	4	56

ROBLEM XV.

...dian line, or to find the cardinal ... of the compass, by equal altitudes of the ... or a star.

...f equal altitudes of the sun be taken, as ...cted in problem xiii, and the place of the ...ex on the horizon circle be carefully noted ...t each time of observation, the middle degree or part between each, will be the place where the index will stand, when the sights of the quadrant are directed to the south, or north, according as the sun is to the southward or northward of the place of observation at noon. Set the index to this middle point, and direct the sights of the quadrant to some remote and fixed object on the earth. This object will be a south meridian mark, and will serve to set the quadrant at any future time. Then take up the instrument, and after setting the index to o, place it again on the table, or support, and move the whole instrument, not by any of it's parts, but entirely about upon the table, till the sights are truly directed to the meridian mark. Adjust the horizontal circle by prob. i, and the index will then serve to shew the true bearing of any object; because the diameter joining the two zeros, or oo's, answers to the meridian line.

If the table, or supp
will be proper to make
tions, to receive the poi
which means the horizo
ſtantly, at any time, ſet in
with reſpect to the cardinal
rizon.

It often happens that there is not an
dow in a houſe, from which the ſun can be
morning and evening. In this caſe, the m
dian may be determined by obſervations of
equal altitude of the pole-ſtar, or any other near
the pole.

Problem XVI.

To find the time by the ſun's tranſit over the meridian.

Adjuſt the quadrant to the cardinal points by the laſt problem, a ſhort time before noon. Set the index to o, and elevate the quadrant, ſo that the ſhadow of the ſight with the croſs wire may fall upon the other. As the inſtant of apparent noon approaches, the bright ſpot formed by the ſun's light through the lower hole in the former ſight, will be ſeen approaching the mark on the latter. If the obſerver chuſes to look at the ſun, he muſt now put up the dark glaſs, and apply to the obſervations. The inſtants when the firſt limb, or edge of the

...e perpendicular wire, ... limb appears to leave ...e clock or watch. The ...pparent noon. Or if he ...y the bright ſpot only, the ...pot is ſeen upon the mark is ...en... ...n; and this, corrected by the ...n of time, will ſhew how much the clock ... or ſlow.

Problem XVII.

To find the time by an obſervation of the ſun's altitude and azimuth.

Adjuſt the inſtrument to the cardinal points, and obſerve the ſun's altitude. Take notice likewiſe of the angle of azimuth from the meridian, as ſhewn by the index.

Then,

As the ſine complement of the ſun's declination
Is to the ſine complement of the altitude;
So is the ſine of the azimuth
To the ſine of the ſun's horary angle.

Which laſt being reduced into time, by allowing fifteen degreees to one hour, and in proportion for the other parts, gives the apparent time, if afternoon; but if before noon, it muſt be deducted from 12 hours, to give the time.

This apparent time i...
equation of time.

Example. Suppoſe, ...
June, the ſun's altitude ...
46° 25′, and his azimuth 1...
tion being 23° 29′.

As the coſine of the ſun's ...
tion 23° 29′ - ...

Is to the coſine of the altitude
46° 25′ - 9.8...

So is the ſine of the azimuth
112° 59′, or 67° 1′ - 9.96...

19.80255...
9.9624527

To the ſine of the horary angle
43° 47′ 13″ - 9.8401039

As 15° to 1h, ſo is 43° 47′ 13″ to 2h 55′ 8″, the apparent or true time paſt noon, to 9h 4′ 52″ before noon; but neither of theſe times will agree with a watch which meaſures time equally.

The equation of time for noon at Greenwich is 1′ 15.9″, the daily difference 13″; therefore, as 24h is to 13″, ſo is 2h 55′ 8″ to 1.5″; conſequently 1.5″ added to 1′ 15.9″, or 1′ 17.4″, is the equation of time to be added

t 2h 55′ 8″ added to
the time paſt noon per

y to remark, that when-
e equation of time to that
l from calculation, you
is the Nautical Ephemeris
d if the time is not very near noon,
make a proportion as above; but if
ply the equation of time to the time per
you muſt ſubtract where the ephemeris
you to add, and *vice verſa.*

PRACTICA

OF

EQUATO

OR

UNIVERSAL SUN-D

AND IT'S USES

THE *plumb-line*, or direction in which
vity acts, being the only line we can at times have immediate recourse to, for determining the position of objects, is the chief particular to which the circles in the instrument last described are adapted; and accordingly their planes are placed the one parallel, and the other perpendicular to that line. But as there are few places on the earth, whose vertical or horizontal circles correspond with those in which the celestial motions are performed, it was found necessary, at a very early period, to construct instruments adapted not only to the measurement of altitudes and azimuths, but also to follow the heavenly bodies in their respective paths, and determine their right ascensions and declinations, more im-

by the quadrant and
uatorial is the moſt ap-
nt for this purpoſe.
following parts ;
ne E F, plate XIV, fig. 2,
f the former inſtrument,
nts, of 90° each. But inſtead
ble index, there is a fixed nonius
and the circle itſelf may be turned on

center of the horizonal circle is fixed
upright pillar, which ſupports the cen-
a verticle ſemicircle A B, divided into
uadrants of 90° each. This is called the
rcle of altitude, and ſupplies the place of
quadrant in the former inſtrument ; but it is more extenſively uſeful, becauſe one quadrant ſerves to meaſure altitudes, and the other depreſſions. It has no plumb line, but a nonius plate at K.

At right angles to the plane of this ſemicircle, the equatorial circle M N is firmly fixed. It repreſents the equator, and is divided into twice twelve hours, every hour being divided into twelve parts, of five minutes each.

Upon the equatorial circle moves another circle, with a chamfered edge, carrying a nonius, by which the diviſions on the equatorial

may be read off to fin
angles to this moveable
circle of declination D,
rants of 90° each.

The piece which carri
fixed to an index moveable
declination, and carrying a noi
fight O, to which the eye is to be ap
two fmall holes, and a dark glafs f
either occafionally; and the fight
pieces fcrewed on, the lower having
to admit the folar ray, and the up
two crofs wires.

Laftly, there are two fpirit lev
the horizontal circle at right angles
other.

The following are among the many problems which may be folved with peculiar facility, by means of this ufeful inftrument.

PROBLEM XVIII.

To adjuft the equatorial for obfervation.

Set the inftrument on a firm fupport. Firft, to adjuft the levels, and the horizontal or azimuth circle. Turn the horizontal circle, till the beginning O of the divifions coincides with the middle ftroke of the nonius, or near it. In this fituation, one of the levels will be found

joining the two foot-
t the nonius, or elſe pa-
e. By means of the two
cauſe the bubble in the
onary in the middle of the
horizontal circle half round,
ther O to the nonius; and if
remains in the middle, as before, the
adjuſted; if it does not, correct the
he level, by turning one or both of
which paſs through it's ends, (by
turn-ſcrew,) till the bubble has moved
ance it ought to come to reach the
caufe it to move the other half, by
foot ſcrews already mentioned. Re-
horizontal circle to it's firſt poſition, and if the adjuſtments have been well made, the bubble will remain in the middle; if otherwiſe, the proceſs of altering the level and the foot-ſcrews, with the reverſing, muſt be repeated till it bears this proof of it's accuracy. Then turn the horizontal circle till 90° ſtands oppoſite to the nonius; and by the the foot-ſcrew, immediatly oppoſite the other 90°, (without touching the others,) cauſe the bubble of the ſame level to ſtand in the middle of the glaſs. Laſtly, by it's own proper ſcrews ſet the other level (not yet attended to) ſo that it's bubble may occupy the middle of it's glaſs.

Secondly, to adju[illegible]
the nonius on the de[illegible]
the nonius on the horai[illegible]
nonius on the ſemici[illegible]
Look through the ſights [illegible]
the horizon, where there is [illegible]
objects. Level the horizon[illegible]
then obſerve what object appears [illegible]
of the croſs wires. Reverſe th[illegible]
altitude, ſo that the other 90° m[illegible]
nonius; taking care at the ſame [illegible]
other three noniuſes continue [illegible]
of their reſpective graduatio[illegible]
the remote object continues [illegible]
center of the croſs wires, the l[illegible]
truly adjuſted; but if not, unſcrew [illegible]
ſcrews which carry the frame of the croſs wires, and move the frame till the interſection appears to lie on a new object, half way between the object firſt obſerved, and that to which the wires are applied in the laſt poſition. Return the ſemicircle of altitude to it's original poſition: if the interſection of the wires be then found to be on the object to which they were laſt directed, the line of ſight is truly adjuſted; but if not, the frame muſt be again altered as before: and the ſame general operation muſt be repeated, till the croſs wires in both poſitions apply to the ſame object.

of the center of in-
that one of the wires
of the declinarion femi-
right angles to that
are fixed at right angles
djuftment of one of them
. For this purpofe, obferve
on one of the wires; if it be
re, move the index of the femi-
ation; or if the other, move the
femicircle on the axis of the
In either cafe the object will
wire during it's motion, if the
, if not, alter that pofition, ta-
to difplace the center from it's
juftment.

To adjuft the piece which carries the hole for forming the folar fpot, direct the fights to the fun, fo that the center of the luminous circle, formed by the aperture which carries the crofs wires, may fall precifely on the upper fight-hole. Then move the frame, with the fmall perforation, till the folar fpot falls exactly on the lower fight-hole.

Thirdly, to find the correction to be applied to obfervations by the femicircle of altitude. Set the nonius on the declination femicircle to O, and the nonius on the horary circle to XII; direct the fights to any fixed and diftant

object, by moving
femicircle of altitud
the degree and mir
fion ; reverfe the dec
recting the nonius on
oppofite XII ; direct t
fame object, by means of the
and femicircle of altitude, a
altitude, or depreffion, be the
ferved in the other pofition,
be required ; but if otherwife
ence of the two angles is the
added to all obfervations or
with that quadrant, or half
which fhew the leaft angle ; or
from all obfervations or rectifications made
the other quadrant, or half.

When the levels and crofs wires are once truly fet, they will preferve their adjuftment a long time, if not deranged by violence ; and the correction to be applied to the femicircle of altitude is a conftant quantity.

PROBLEM XIX.

To meafure angles, either of azimuth, altitude, or depreffion.

Set the middle mark of the nonius on the declination at O, and fix it by means of the milled fcrew behind. Set the horary circle at

e inftrument (pre-
observation. Then
ceffively to any two
minutes contained be-
of the nonius, on the
circle, will fhew the ho-
fame manner as has been de-
ii, of the quadrant. And
ghts be directed to any object,
horizontal circle and femicircle
degree and minute marked by
laft-mentioned femicircle will
titude, if on the quadrant or
ye, or of depreffion, if on the
nt.

Remark. It is proper in this place to defcribe the nature and ufe of the admirable contrivance commonly called a *nonius*. It depends on the fimple circumftance, that if any line be divided into equal parts, the length of each part will be greater, the fewer the divifions; and contrariwife, it will be lefs in proportion as thofe divifions are more numerous. Thus it may be obferved, that the diftance between the two extreme ftrokes on the nonius, in the equatorial before us, is exactly equal to eleven degrees on the limb, but that it is divided into twelve equal parts. Each of thefe laft parts will therefore be fhorter than the degree in the proportion of 11 to 12; that is to

550

ſay, it will be one-
ſhorter. Conſeque
ſet preciſely oppoſite
poſitions of the noni
tered five minutes of
the two adjacent ſtrokes
nonius, can be brought to
neareſt ſtroke of a degree ;
ſecond ſtrokes on the nonius
change of ten minutes, the thir
ſo forth to thirty, when the mi
nonius will be ſeen to be eq
two of the ſtrokes on the lin
the lines on the oppoſite ſide
coincide in ſucceſſion with the
limb.

It is clear from this, that whenever the middle ſtroke of the nonius does not ſtand preciſely oppoſite to any degree, the odd minutes, or diſtance between it and the degree immediately preceding, may be known by the number of the ſtroke on the nonius, which coincides with any of the ſtrokes on the limb. It muſt be obſerved, however, that as the degrees in ſeveral quadrants are reckoned in oppoſite directions, ſo likewiſe the nonius has two ſets of numbers: for the uſe of which, it need only be remembered, that they always begin from the middle, and go to 30 minutes, and thence from

...he ſame direction to
...muſt always be reck-
...on to the degrees on

...BLEM XX.

...nce of an object on the earth, by
...ns made at two ſtations.

... done by meaſuring a baſe line
...tal angles, and proceeding as
... ii. But as the equatorial
...s of depreſſion as well as ele-
...on, the ſtations may not only be on the ſame level, but may be vertically the one above the other. For example, if the altitude of any object be taken from a lower window of any building, and it's depreſſion from a window immediately above, and the diſtance of the two ſtations of the inſtrument be accurately meaſured,

* In this inſtrument they muſt be read in the oppoſite direction; but when the nonius plate has it's diviſions fewer than the number of parts on the limb to which it is equal, they coincide ſucceſſively in the ſame direction as that of the motion of the index.

Then,
As the fine of the
and depreffion, (
be altitude, or bo
Is to the fine of the ar
So is the diftance betwe
To the diftance of the o
ftation.

Example 1. From
tom of a houfe, the a
fig. 9, plate XV, of an obj
be 40°; eighteen feet above
fition, the angle B D E was
37° 30′.

Then,
As fine of the difference of th
two angles 2° 30′ -
Is to fine angle B D C, equal an
B D E, plus 90 127.3
So is D C 18 feet

11.1547392
8.6396796

To B C, the required diftance,
327.38 feet 2.5150596

Example 2. From C, fig. 10, plate XV, a window near the bottom of a houfe, the angle B C A of elevation of B was found to be 15°

ingle of depreſſion

les 25° 9.6259483
9.9933515
1.2552725

11.2486240
9.6259483

1.6226757

OBLEM XXI.

re heights and diſtances.

circle of altitude anſwers every
quadrant, in the inſtrument be-
nd the horizontal circle is com-
will be eaſy for the intelligent
rm the problems iii, iv, vii, viii,
quatorial, from the inſtructions
each reſpectively.

PROBLEM XXII.

To plot a piece of land.

The problems v, and vi, with all others which are ſolved by the menſuration of horizontal angles, may likewiſe be performed with facility by the equatorial.

PROBLEMS XXII

Under this title it
problems xi, xii, xiii, x
for finding the latitud
tudes, the position o
the time by the sun's tr
or by it's altitude and
ed with equal ease, an
horizontal circle and sen
instrument before us, as by 'art
of under those problems.

I shall now proceed to three
to which the equatorial is nor
ted.

PROBLEM XXVII.

To find the latitude of the place by
known fixed star.

The instrument being adjusted according to the directions already given, set the semicircle of altitude to 90, and when the sun is coming near the meridian, elevate the sights till the center of the sun is exactly in the center of the cross wires; then follow the sun,

l and declination
's at his greateſt
eclination will then
e, from which ſub-
be north, or add it if it
r, if north, and the ſum,
e equator, that is, the
; from which ſubtract
oned by refraction, and
rom 90° gives your la-

ved meridian			
n's lower limb	44°	51′	23″
ne ſun -		16	
center -	45	7	23
h -	6	57	37
uator, or co-lati-			
-	38	9	46
fraction -		5	54
Co- orrected -	38	3	52
Which ſubtracted from 90° gives the latitude - -	51	56	8

The latitude may be obtained in the ſame manner by a fixed ſtar, whoſe declination is known.

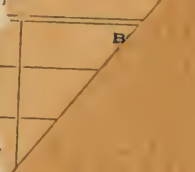
P

To find the meridian
ONE OBSERVAT
declination an
known.

This problem re
muth and altitude
quickly; and this is
case more eminently, the fart
is from the meridian. Theref

al and geographical
s.

At the distance of three
either before or after noon
zontal circle; set the semi
that it's nonius may stand
lay the plane of the last-
in the meridian, by estim
directed towards the depressed
nonius of the declination sem
clination, whether north or so di-
rect the line of sight towards the by
moving the declination semicirc axis
of the equatorial circle, and part moving
the horizontal circle on it's own There
is but one position of these which will admit of
the solar spot falling directly on the mark on
the opposite sight. When this position is ob-



torial, or horary
, and the circle
lane of the meridian.

XIX.

atitude, the ſun's
n, are known.

found by equal alti-
ar, which is the beſt
y a meridian mark,
, to ſet the ſcrews in, place
accordingly, and adjuſt it by
the ſemicircle of altitude to
he place, and the index of
the declination of the ſun.
rcle, till the ſights are ac-
the ſun. The nonius will
e horary circle.

hi ... is more accurate than the
... may be applied at all times
wh ... s viſible.